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# Good Agricultural Practices for African Indigenous Vegetables

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# Good Agricultural Practices for African Indigenous Vegetables

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Editors: R. Nono-Womdim, C. Ojiewo, M. Abang, Mel O. Oluoch

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**Cover Photos** (courtesy of R. Nono-Womdim)

A. Amaranthus harvest ready for sales/peri-urban vegetable production in Kinshasa, Democratic Republic of Congo.

B. Fruits of different okra varieties found in west Africa.

C. African eggplant (*Solanum aethiopicum*).

# PREFACE

Over the next four decades, world population is projected to grow by almost one-third, to more than 9 billion people, of which almost 70 percent will be living in urban areas by 2050. To feed the growing population, farmers in the developing world must intensify and diversify food production, a challenge made even more daunting by the combined effects of climate change and growing competition for land, water and energy. The intensification of production systems and their diversification to vegetable crops, especially indigenous vegetable species, could make a significant contribution to meeting increased demand for food.

Indigenous vegetables are important to food security, nutrition and income in many countries of sub-Saharan Africa. However, owing to the lack of resources allocated for the development of the vegetable subsector, they have not received the attention they deserve. Until recently, research and development efforts have focused mainly on improving production systems for exotic vegetables, and have paid little attention to more diverse and abundant indigenous species and varieties, and the ways in which they are used.

The purpose of this publication is to assemble and disseminate existing knowledge on sustainable production and utilization of African indigenous vegetables. While it does not pretend to cover every species of African indigenous vegetable that contributes to food and nutrition security, it presents good agricultural practices and information on the utilization of those species that are most popular in the region.

The Plant Production and Protection Division of FAO is committed to supporting initiatives and promoting synergies among organizations that promote the production and consumption of African vegetables species for improved livelihoods, health and incomes of vulnerable groups and local population in sub-Saharan Africa.

This publication is intended to inform policy and decision-making at national and regional levels; it will interest a wide range of readers including development organizations, NGOs as well as researchers and professionals in agriculture.

Shivaji Pandey
Director
Plant Production and Protection Division
FAO, Rome, Italy

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# STATEMENT

The opinions expressed in this book are those of the authors and do not necessarily reflect the views of their respective organizations.

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# Introduction to the Workshop on Good Agricultural Practices for African Indigenous Vegetables

**Rémi Nono-Womdim**

*FAO Plant Production and Protection Division*
*Rome, Italy*

## THE CHALLENGE

Since plants were first domesticated, African societies have used indigenous vegetables to meet their nutritional needs. Depending on the region considered, most of these indigenous vegetables are found as weeds in wild and/or cultivated areas, are semi-cultivated, or are grown as crops that require very little management or additional inputs.

It is generally believed that African indigenous vegetables are old-fashioned foods used mainly by "backward" rural people and destined to be superseded by "more modern" vegetable species. However, the evidence shows that these plants are rich in micronutrients, are crucial to the household food security of millions of low income people, and are emerging as cash crops as demand increases in most sub-Saharan countries. In nearly two-third of the households in Cameroon, for example, leafy vegetables are prepared from four to seven times a week. Nutritional studies have shown that African vegetables such as amaranth have higher levels of protein, vitamins (A and C), carotene and minerals, compared to cereals and fruits (AVRDC, 2001). Moreover, numerous studies conducted in sub-Saharan Africa have shown that African indigenous vegetables are important for both subsistence production and income generation, especially in urban and peri-urban cropping systems (Shackleton et al., 2009).

Despite the contribution of indigenous vegetables to food security, nutrition and income, the lack of resources allocated for the development of the vegetable sector has meant that in most African countries they have not received the attention they deserve. Until recently, most research and development efforts have focused on improving production systems for exotic vegetables, and have ignored the more diverse and abundant indigenous species and varieties and the ways in which they are used.

## EARLIER INITIATIVES FOR INTERNATIONAL COLLABORATION ON AFRICAN INDIGENOUS VEGETABLES

The last two decades have witnessed growing awareness of the limitations of the Green Revolution, the interactions between agriculture and environment, the challenge of climate change, and the role of a diversified diet in ensuring good health. One consequence has been increasing recognition within the international community of the need for promoting production and consumption of African indigenous vegetables.

As early as 1990, the World Vegetable Center (AVRDC) launched a regional programme for Africa. AVRDC has given high priority to vegetables – including African indigenous vegetables – that are strategically important in the major regions of Africa and are considered as *regional commodities* (Opeña and Nono-Womdim, 1996; Nono-Womdim and Opeña, 1997). During the same period, the sub-Saharan Africa office of Bioversity International (formerly IPGRI) organized a workshop on "Genetic resources of traditional vegetables in Africa: conservation and use". The workshop, which grew out of the CTA/IPGRI/KARI/UNEP seminar "Safeguarding the genetic basis of Africa's traditional crops" held in October 1992 in Nairobi, recommended that more attention be paid by the plant

genetic resource conservation community to relatively neglected species, in particular indigenous vegetables and other so-called “minor” crops (Attere and Guarino, 1997). With increased donor interest and funding, the 1990s saw an expansion in projects, networks and conferences, which has continued strongly during the past decade (Jaenicke et al., 2006). In March 2008, the International Society for Horticultural Science (ISHS) organized a symposium on underutilized plants for food security, nutrition, income and sustainable development, which brought together more than 200 participants from 55 countries. The symposium has reinforced collaboration, coordination and exchange among scientists and institutions (Jaenicke et al., 2009).

## THE SCOPE OF THE WORKSHOP

Good Agricultural Practices (GAP) is a multidisciplinary area of work in FAO which is attracting a significant and growing demand for assistance from member countries. FAO has developed a GAP database which brings together key FAO documents and publications, as well as selected non-FAO sources, in electronic format.

Numerous scientists and institutions have been involved in research initiatives on African indigenous vegetables. However, relevant information on GAP for African indigenous vegetables remains very scarce. The major objectives of the workshop, therefore, are to:

- Review and exchange information on Good Agricultural Practices for selected African indigenous vegetables;
- Identify major constraints to the promotion of sustainable and safe production and use of African vegetables, especially in urban and peri-urban cropping systems;
- Discuss collaborative initiatives on the sustainable production of African indigenous vegetables and explore opportunities and ways of forging links among scientists and institutions.

From its initiatives for urban and peri-urban horticulture development, FAO has found that there is a growing demand for indigenous vegetables in African cities and urban consumers are more and more concerned about the safety of their food.

The outcomes of this workshop are expected to complement ongoing FAO efforts in both GAPs and urban and peri-urban horticulture.

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# Good Agricultural Practices for Underutilized Vegetables in Sub-Saharan Africa: Current Status and Future Perspectives

**Mary O. Abukutsa-Onyango**

*Department of Horticulture, Jomo Kenyatta University of Agriculture & Technology, P.O. Box 62000, 00200 Nairobi, Kenya*
*(mabukutsa@yahoo.com)*

**Abstract**

Agriculture is sub-Saharan Africa's largest area of economic activity, yet food insecurity and malnutrition continues to worsen. In order to overcome the unique problems facing Africa there is need for a paradigm shift in the food production and consumption patterns. The objective of the paper is to examine the current status and future prospects of good agricultural practices for underutilized vegetables in sub-Saharan Africa. Good agricultural practices are a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economical, social and environmental sustainability. It focuses on economically and efficiently producing sufficient, safe and nutritious food; sustaining and enhancing natural resources; maintaining viable farming enterprises, and thereby contributing to improved and sustainable livelihoods. Some of the established GAPs include, but are not limited to, EurepGAP, FAO GAP Principles, UgaGAP, KenyaGAP and GLOBALGAP. Underutilized vegetable species have the potential to contribute to food security, nutrition and health; generate income and sustain the environment; but are currently under-exploited. Historically, underutilized vegetable species have been cultivated widely and consumed as food but several are being abandoned and are now cultivated only in limited areas. Many of such species are species indigenous to Africa which have been neglected as a result of new introduced exotic species that have replaced them due to pressure of evolving consumer preferences, lifestyles, socioeconomic realities and cultural values. They are mostly gathered from the wild or are grown by local farmers for subsistence using traditional methods. Underutilized vegetables are also known as neglected, abandoned, orphaned, underused, lost, minor, traditional or forgotten vegetable species. Some of the identified indigenous vegetables in sub-Saharan African include: *Amaranthus* spp., African vegetable nightshades, traditional vegetable cowpeas, jute mallow, African okra, spiderplant, and African eggplant. Currently, efforts are being made on the continent to develop good agricultural practices and promote sustainable production and utilization of the underutilized vegetables by national research organizations, international research organizations, universities, NGOs and Ministries of Agriculture and Environment. Some of the work that has been done by these organizations include: identification of priority underutilized vegetables; collection, characterization, selection of promising species; bulking, packaging and distribution of quality seed; development of technical crop production technical packages, development of recipes and products; advocacy, outreach and dissemination. The future prospect is envisaged to be a focus on the development of good agricultural practices for promising vegetables, development of an efficient seed system, breeding, conservation, commercialization, processing, value addition, and product development of underutilized vegetables in sub-Saharan Africa. It is therefore imperative to develop GAP for underutilized vegetables to fully exploit their potential and to solve the problems of hunger, malnutrition, poor health and poverty that are prevalent in sub-Saharan Africa.

**Keywords:** sustainable, production, utilization, vegetables, underutilized, food security, health, wealth

## INTRODUCTION

Agriculture is sub-Saharan Africa's largest area of economic activity, accounting for 40% of gross domestic product (GDP) and 60-80% of employment. Despite this fact, food insecurity and malnutrition continue to worsen. Over 50% of the people in sub-Saharan Africa live below the poverty line (AICAD, 2003; Weblow, 1996). For optimal productivity to be achieved, strong public research institutions are mandatory to generate key agricultural technologies as well as effective linkages with the private sector that can scale up and disseminate these technologies to the farmers. Although sub-Saharan Africa is endowed with a diversity of indigenous vegetables, many people prefer exotic foods (Chweya and Eyzaguirre, 1999; Schippers, 2002; Abukutsa-Onyango, 2007a; Abukutsa, 2010). In order to overcome the unique problems facing Africa there is need for paradigm shift in the production and consumption patterns. It is challenging to develop agriculture in Africa based on the model of agricultural development in the West or following green revolution principles and this is further complicated by emerging global challenges like climate change, energy gap and global economic crisis. This therefore calls for strategies that will ensure both sustainability and sustainagility in production and contribution in order to meet the Millennium Development Goals. The objective of the paper is therefore to examine the current status and future prospects of good agricultural practices for underutilized vegetables in sub-Saharan Africa.

## GOOD AGRICULTURAL PRACTICES OF INDIGENOUS VEGETABLES IN SUB-SAHARAN AFRICA

Good agricultural practices are a collection of specific methods, which when applied to agriculture, produce results that are in harmony with the values of key stakeholders along the product supply chain. They are a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economical, social and environmental sustainability. It focuses on economically and efficiently producing sufficient, safe and nutritious food; sustaining and enhancing natural resources; maintaining viable farming enterprises, and thereby contributing to improved and sustainable livelihoods. Some of the established GAPs include but are not limited to EurepGAP, FAO GAP Principles and GLOBALGAP (Wikipedia, 2009).

Good agricultural practices may be applied to a wide range of farming systems and at different scales. They are applied through sustainable agricultural methods, such as integrated pest management, integrated fertilizer management and conservation agriculture. They rely on four principles: economically and efficiently produce sufficient (food security), safe (food safety) and nutritious food (food quality); sustain and enhance natural resources; maintain viable farming enterprises and contribute to sustainable livelihoods; meet cultural and social demands of society. The concept of GAPs has changed in recent years because of a rapidly changing agriculture, globalization of world trade, food crisis (e.g. mad cow disease), nitrate pollution of water, appearance of pesticide resistance, soil erosion, etc.

Good agricultural practices are being developed and applied by governments, NGOs and private sector to meet farmers and transformers needs and specific requirements. They provide the opportunity to assess and decide on which farming practices to follow at each step in the production and product delivery process. For each agricultural production system, they aim at allowing a comprehensive management strategy, providing for the capability for tactical adjustments in response to changes. However, many think these applications are only rarely made in a holistic or coordinated way. The implementation of such a management

strategy requires knowing, understanding, planning, measuring, monitoring, and record-keeping at each step of the production process. Compliance with Good Agricultural Practices has human, physical and social capital implications. Adoption of GAPs may result in higher production, transformation and marketing costs, hence higher overall production costs and higher prices for the consumer. GAPs require maintaining a common database on integrated production techniques for each of the major agro-ecological areas, to ensure the collection, analysis and dissemination of information on good practices in relevant geographical contexts. EurepGAP was a common standard for farm management practices in the late 1990s based on the Food and Agriculture Organization's (FAO) Hazard Analysis Critical Control Points (HACCP) guidelines which changed to GLOBALGAP in September 2007 (Wikipedia, 2009). GLOBALGAP sets voluntary standards for the certification of agricultural products around the globe. Appropriate local GAP could be developed from the GLOBALGAP or FAO principles and guidelines that include soil management, water management, crop protection, harvest management and on farm processing aspects. Governments in sub-Saharan Africa should endeavour to adapt GLOBALGAP and ensure that it is applied to local production and processing of diverse commodities (including underutilized vegetables) for both the export and local markets. Most of the EurepGap certified farms in Kenya were those growing for the export market. Currently, Kenya is in the process of localizing the GLOBALGAP by developing a KenyaGAP. In the development of KenyaGAP it is mandatory to bear in mind the entire value chain in the production process of any commodity as illustrated by figure 1 of African Leafy Vegetable value chain in Kenya.

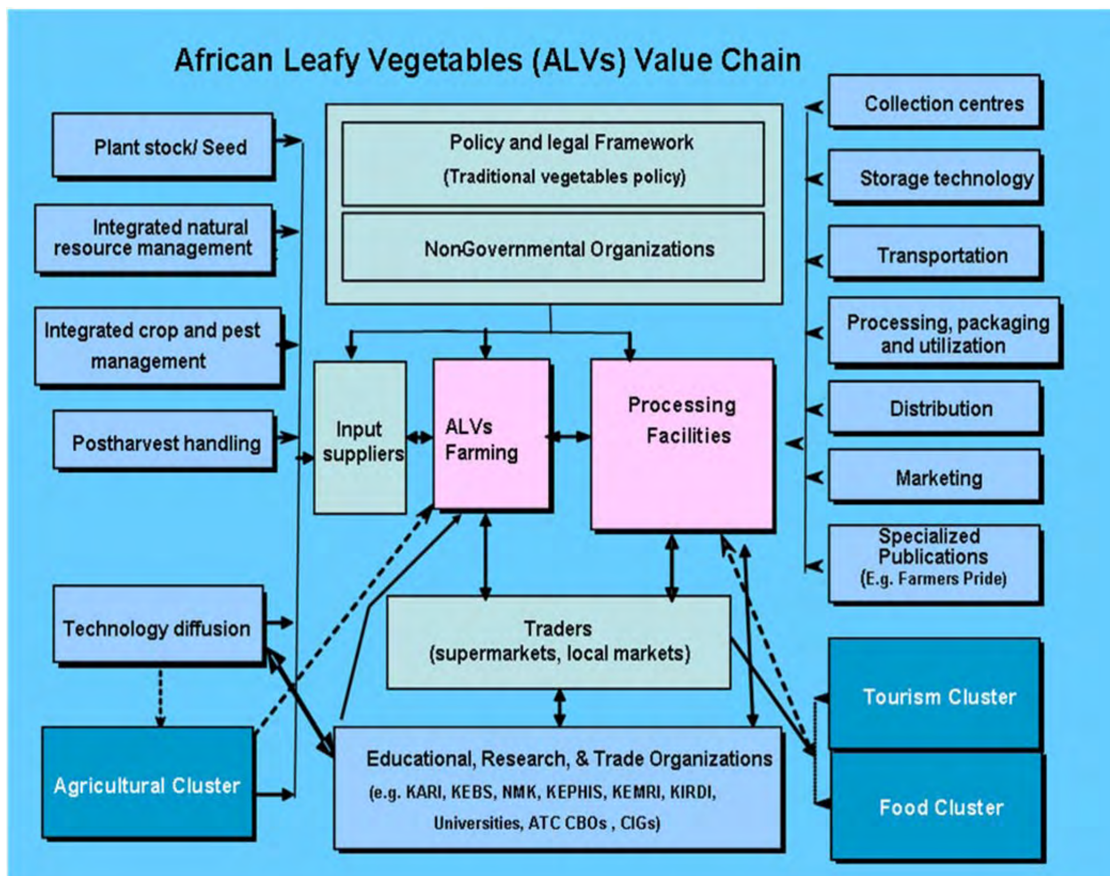


**Figure 1: African indigenous vegetable value chain.**

Good agricultural practices apply for on farm production and post-production processes. The main challenges in these processes with regard to indigenous vegetables include: low yields, food safety issues, climate change, food and nutrition insecurity, short shelf life and environmental degradation. In on farm production these challenges include: low yields,

improper manure and fertilizer use, biological contaminants from manure that is not properly decomposed, insect and pest control using pesticides resulting in high pesticide residue levels, urban and peri-urban production and road side gardens leading to accumulation of heavy metals, inadequate moisture supply due to climate change, and the need for drought tolerant species and fast maturing crops. On the other hand, in post-production processes, including harvesting and post-harvest handling, biological contaminants and foreign materials should be avoided. Packaging and transportation should be done to minimise breakage and tissue rupture that predispose the produce to penetration of pathogens. In marketing, the market infrastructure should ensure that there is minimal contamination from dust and other environmental contaminants especially in the open air markets. In the last post-harvest processing and preparation the consumer has to prepare the vegetables so that they retain as much of the nutrients as possible and reduce the perishability of the produce. Recipes and cooking methods should be simple and retain as much of the nutrients as possible. Since most of the vegetables are highly perishable there is need to develop quality products that could contribute to alleviation of the malnutrition problems in sub-Saharan Africa.

## UNDERUTILIZED VEGETABLES

Indigenous vegetables are considered to be underutilized crops although this perception may be partly based on scarcity of data (Weinberger, 2007). In this paper indigenous vegetables refer to crop species or varieties that are indigenous or endemic to a region, or to a crop species introduced into a region where over a period of time it has evolved and become part and parcel of the culture and tradition of a people (Maundu et al., 1999; Weinberger, 2007). Underutilized vegetable species have the potential to contribute to food security, nutrition and good health; generate income and sustain the environment; but are currently under-exploited. Historically, underutilized vegetable species have been cultivated widely and consumed as food but some are now being abandoned and cultivated only in limited areas. Many of such species are the species indigenous to Africa which have been neglected as a result of new introduced exotic species that have replaced them due to pressure of evolving consumer preferences, lifestyles, socioeconomic realities and cultural values (Hughes, 2009). They are mostly gathered from the wild or are grown by local farmers using traditional methods in their centres of origin for subsistence of the people in the area. Underutilized vegetables are also known as neglected, abandoned, orphaned, underused, lost, minor, traditional or forgotten vegetable species. The value and importance of African indigenous vegetables include: nutrition – have high content of micro-nutrients; health benefits contain anti-oxidants and fiber that aids digestion; nutraceuticals; garnishing dishes and appetizers; several agronomic advantages and economic importance and potential (Schippers, 2002; Makokha and Ombwara, 2005; Abukutsa, 2010). The major challenges of production include: inadequate quality seed; food safety issues; low yields and production; short shelf life; technical issues; climate change; environmental degradation; negative attitudes and policy issues.

## CURRENT STATUS

Production of African indigenous vegetables in sub-Saharan Africa is largely for subsistence with home gardens, market gardens, peri-urban and urban production, and organic production systems (Oluoch et al., 2009). Commercial production, controlled environment production and use of hydroponics and aeroponics systems is yet to come into play. The current system is characterized by low production compared to other vegetable crops as shown in Table 1.

In marketing, indigenous vegetables constitute less than 10% of the marketed vegetable commodities in Kenya (Abukutsa-Onyango, 2002) and most of the marketing is done in the open air or wet markets. Efforts made on the continent by various stakeholders to promote sustainable production and utilization of indigenous vegetables has resulted in the vegetables penetrating supermarkets and raising their status (Irungu, 2007).

**Table 1: Low annual production of AIVs in Kenya (2007)**

(Source: Ministry of Agriculture, Kenya, Annual Report, 2007).

| Vegetable | Tonnes |
|---|---|
| Tomato | 250,0000-350,000 |
| Cabbage | 250,000-350,000 |
| Kale | 250,000-350,000 |
| Onion | 60,000 |
| Indigenous vegetables | 70,000 (6% contribution) |

Research by national research organizations, international research organizations, universities, NGOs and Ministries of Agriculture and Environment have concentrated on the following areas: identification of priority underutilized vegetables; collection, characterization, selection of promising species; bulking, packaging and distribution of quality seed; development of technical agronomic packages; physiological studies; development of recipes and products; advocacy, outreach and dissemination (Abukutsa-Onyango 2007b, 2009a; Abukutsa, 2010).

Some of the identified underutilized indigenous vegetables in sub-Saharan Africa include: vegetable amaranths (*Amaranthus blitum* and *A. cruentus*), African vegetable nightshades (*Solanum scabrum*, *S. villosum*, *S. americanum*), traditional vegetable cowpeas (*Vigna unguiculata*), jute mallow (*Corchorus olitorius*), African okra (*Abelmoschus caillei*), spiderplant (*Cleome gynandra*), moringa (*Moringa oleifera*), African egg plant (*Solanum anguivi*, *S. aethiopicum*, *S. macrocarpon*), pumpkin (*Cucurbita pepo*, *C. moschata*, *C. maxima*, *C. mixta*), vine spinach (*Basella alba*) and Bambara groundnut (*Vigna subterranean*) (Pasquini et al., 2009; Abukutsa-Onyango, 2007a; Abukutsa-Onyango et al., 2007; AVRDC, 2002). Vegetable amaranths and African vegetable nightshade are found in the three regions of eastern, southern and western Africa, but the highest diversity has been recorded in eastern Africa, in the Lake Victoria basin.

Development and documentation of sustainable technical protocols and packages for the priority African indigenous vegetables have been achieved (Abukutsa-Onyango, 2009a; Abukutsa, 2010). Physiological studies, ex situ and in situ conservation of AIVs, development of recipes and products and breeding aspects have been initiated in several research institutions and universities.

Capacity building on different aspects of African indigenous vegetables for farmers, extension workers, researchers and students has been conducted and is ongoing at some of the institutions in sub-Saharan Africa notably AVRDC-The World Vegetable Center and in universities in Kenya, Nigeria, etc. Inclusion of AIVs in the BSc and MSc Horticulture programmes has been implemented at Maseno University and is in progress at Jomo Kenyatta University of Agriculture and Technology (Abukutsa-Onyango, 2009b), Moi University and University of Nairobi.

As a result of sensitizing students and inclusion of AIVs in the undergraduate programs there has been an increased number of students taking research projects on AIVs as shown in Table 2.

Recipes and products of priority AIVs have been developed and documented (Habwe et al., 2009a, b). Some of the recipes have been tested not only for palatability and acceptance but also for nutrient content. Due to the high perishability of AIVs drying and packaging methods are being developed and tested.

**Table 2: Percentage BSc students who conducted research projects in AIVs at Maseno University and JKUAT in Kenya between 2001 and 2008**

(Source: Abukutsa-Onyango, 2009b)

| Year | Maseno | JKUAT |
|---|---|---|
| 2001 | 20 | - |
| 2002 | 34 | - |
| 2003 | 28 | - |
| 2004 | 71 | 31 |
| 2005 | - | 29 |
| 2006 | 70 | 20 |
| 2007 | 42 | 20 |
| 2008 | 50 | 40 |

Research on African indigenous vegetables has resulted in availability of quality seed, development of production and utilization protocols, increased productivity and availability in supermarkets, besides initiatives for processing and product development which are ongoing. Although some work is currently being done on the underutilized vegetables more efforts need to be done on good agricultural practices along the complete value chain.

## FUTURE PERSPECTIVES

Future perspectives for underutilized vegetables in sub-Saharan Africa include: development of GAP through the value chain for quality products; development of an efficient seed system; breeding for both yield and quality; expansion of ex situ and in situ conservation of AIVs; intensification of commercialization, processing, value addition and product development; development of sustainable production and utilization packages; conservation of underutilized vegetables for diet diversity; inclusion of AIVs in the school, college and Agricultural University curricula and increased capacity building, promotion and advocacy; development of nutraceuticals and other products from AIVs. African governments need to develop and implement policies and strategies that promote sustainable production and utilization of underutilized vegetables (Abukutsa, 2010).

Future prospects and focus is envisaged to be the development of good agricultural practices for promising underutilized species from on farm production processes to post-production processes for quality products, development of an efficient seed system, breeding, conservation, commercialization, processing, value addition and product development of underutilized vegetables in sub-Saharan Africa. It is therefore imperative to develop GAP for underutilized vegetables to fully exploit their potential in the local and export markets and solve the problems of hunger, malnutrition, poor health and poverty that are prevalent in sub-Saharan Africa.

## CONCLUSIONS AND RECOMMENDATIONS

In conclusion, good agricultural practices and promotion of underutilized crops is currently being undertaken by various research and higher learning institutions. In order to address problems of hunger and malnutrition in sub-Saharan Africa there should be paradigm shift in production and consumption of underutilized vegetables species by putting strategies in place and developing good agricultural practices along the value chain to optimise their role in sustainability and sustainagility in production.

It is therefore strongly recommended that good agricultural practices for indigenous vegetables be developed and implemented for sustainable and quality production of these vegetables and the development of utilization technical packages and quality products for both the local and export markets be exploited.

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# An Overview on Good Agricultural Practices of African Eggplants (*Solanum* spp.)

**Abdoulaye Seck**

*Concern Universal, PO Box 2164, Serrekunda, The Gambia*
*(abdoulaye.seck@concern-universal.org or aseck44@yahoo.fr)*

**Abstract**

African eggplants include different *Solanum* species of the *Solanaceae* family, subgenus *Leptostemonum* (sections *Melongena* and *Oliganthes*). The main species (*S. anguivi* Lam, *S. aethiopicum* L. and *S. macrocarpon* L.) are grown in Africa and tropical zones for their fruits and leaves. Taxonomic issues still need clarification. *S. aethiopicum* is a polymorphic species comprising 4 groups (Kumba, Gilo, Shum and Aculeatum) previously classified as different species. African eggplants though gradually more popular are still insufficiently explored with regard to diverse aspects (e.g.: plant breeding, seed production techniques and systems, intensive production, etc.).

In this paper, key areas are briefly reviewed with reference to tropical Africa:

- *Floral biology* as influenced by flower morphology and growing conditions is still not well understood.
- *Crop improvement*: Genetic variability is significant. Breeding goals mainly include yield, quality, pest resistance, etc. Hybridization between cultivars of different subspecies is successful; interspecific crossability still needs special attention for gene transfer. Diverse farmers' cultivars are available in addition to OP's[1] developed by breeding programs for different goals (fruit quality, high yield, uniformity, non dormant seeds, mite resistance, etc.) through different methods (e.g.: positive and mass selection, pedigree method, etc.). Other recommended methods discussed are backcrossing, diallel test for hybrid breeding, etc.
- *Cropping systems*: Traditional and recommended practices are briefly discussed (e.g.: seed production, fertilizer application, irrigation, pests and diseases, care, etc.). In particular, research findings on specific pest issues are detailed.
- *Harvest and post-harvest*: plant lifecycles as related to cultivars, environmental conditions, cultural practices and systems, yield ranges, etc., are reviewed.
- *Marketing and uses*: production costs and selling prices are discussed through concrete examples. As well, culinary preparation and use of edible leaves and fruits of different species and varieties are mentioned.

Recommendations relate to further research needed on these aspects with main focus on taxonomic issues, reproductive biology, seed issues, crop improvement, organic production, etc.

**Keywords:** African, eggplants, *Solanum*, *aethiopicum*, *macrocarpon*, *anguivi*, good practices

[1] OP: Open pollinated variety

## BACKGROUND

The *Solanaceae* family comprises about 2,300 species half of which belong to the genus *Solanum*, reported to include about 150 tuberous species (Lester, 1982). This family has been the source of a number of different domesticated species. The *Leptostemonum* subgenus comprises more than 30% of the species of the genus. According to Sekara et al. (2007), the appellation of *eggplant* involves 3 related *Solanum* species of the *Leptostemonum* subgenus, with 2 sections [*Melongena* (*S. melongena* and *S. macrocarpon*) and *Oliganthes* (*S. aethiopicum*)]. However, there seems to be controversies on *S. macrocarpon*'s section considering further research work reported by Sekara et al. (2007) providing evidence of its close relationships with *S. aethiopicum*. The classification of non-tuberous *Solanum* is still difficult due to the large number of species, the important intraspecific variability, the crossability of some species, etc. Accordingly a large number of binomial names have been wrongly attributed to these species (Daunay and Lester, 1988). Lester (1982, 1986, etc.) has significantly contributed to the clarification of the nomenclature of these species, with main focus on *African eggplants*. However, additional work is needed based on more effective methods, etc.

The main non tuberous species cultivated include *Solanum melongena* L., brinjal, native to southern India and widely grown in the world, generally referred to as *European aubergine*. *African eggplants* comprise different species, the most popular of which are *Solanum aethiopicum* L. (scarlet eggplant) and *S. macrocarpon* L. (Gboma) of west and central African origins; the latter is also grown in America and Asia.

*S. aethiopicum* L. is a phenotypically diverse species. It is a fruit and leaf vegetable with hairy or glabrous leaves, bisexual partially self-pollinated flowers; they produce single or grouped fruits (trusses or short cymes) depending on subspecies and varieties (Seck, 1986). The fruits are of varied colour, shape and size (green, white, striped, multicoloured and round to long, smooth, grooved or ribbed and small to very big); they are of bitter to sweet taste depending on their saponin content and consumed cooked or raw. At full maturity, they turn red to orange due to their carotene content.

*S. aethiopicum* (Kumba group) is reported to be highly nutritious. Compared to *S. melongena*, and tomato (*L. esculentum*) 100 g of fruits contain 30% of calories (vs. 25 and 26 for European eggplant and tomato respectively), 9.5% of dry matter (vs. 7.6 and 8.5%), 1.6 g of protein (vs. 1.1 and 1.9), 7.2 g of sugars (vs. 5.8 for both), etc. (Toury, 1965). According to the same author, the leaves of *S. aethiopicum* are 3 times as nutritious as compared to its fruits.

Lester's work (1982, 1986) and report by Lester and Seck (2004) amongst other updates have clarified the taxonomy of several non tuberous *Solanum* (see annex 1). *S. aethiopicum* (scarlet eggplant) comprises the 4 different groups or subspecies described below resulting through a domestication process from *Solanum anguivi* Lam, its ancestor; this species has prickly hairy leaves and stems, flower trusses sometimes bearing over 10 small round to oblong small fruits (less than 1 to 1.5 cm in size); the fruits are green or striped (turning orange to red when fully mature). In some countries, *S. anguivi* is a key vegetable consumed through different varieties.

The domestication process has happened according to the following order (Lester, 1986): *S. anguivi*'s evolution resulted in *S. aethiopicum* group *Gilo* (wrongly referred to as *S. gilo* and *S. anomalum*, more common in savannahs and humid forests). This group evolved and generated the *Kumba* group which through reduction, gave rise to the *Shum* group; however, a different theory reported by Sekara et al. (2007) supports a possible *Shum* origin of the *Gilo* group; according to Lester (1986), the *Aculeatum* group wrongly called *S. integrifolium*

(inedible) resulted from natural crosses between *S. anguivi* Lam and the *Kumba* group of *S. aethiopicum* L. (See figure 2).

**Figure 2: Views of different varieties of *S. anguivi* Lam**

[Sources: Porcher, 2009 (right); ECPGR, 2009 (middle and left)]

Details on the 4 groups of *S. aethiopicum* L. are provided below:

**The Gilo Group:** Very common in the humid tropics (Brazil, Africa); hairy, inedible leaves, variable fruit shape (round, elongated, egg-shaped or spindly, ribbed or smooth), colour (dark and light green, white or striped) and size (from a few to over 100 grams) (See figure 3).

**Figure 3: Fruit size, shape and size in the Gilo group**

[Sources: Porcher, 2009 (A, B, C, E, F, G); ECPGR, 2009 (D, H)]

**The Kumba Group:** Glabrous and large leaves, medium to big ribbed fruits (5-10 cm in diameter), hairless edible leaves. This group is most commonly grown in the arid areas of tropical Africa. Other names are red African eggplant, orange African eggplant, scarlet African eggplant, or mini pumpkin tree (Porcher, 2009) (See figure 4).

**The Shum Group:** Most generally grown for its glabrous edible leaves; its very small slightly flattened, round or elongated fruits, though edible, are scarcely consumed (See figure 5).

**The Aculeatum Group** (= *S. integrifolium*): Plants of this group have inedible leaves and fruits and are rather used as ornamentals (hairy and prickly leaves and stems); fruits are of variable size and shape (round, flattened, ribbed, smooth, etc.), and colour (dark and light green, purple, etc.). This group has been used for pest and disease resistance breeding (Seck, 2000; Lester and Daunay, 2003).

**Figure 4: Variability of fruit size, shape and colour in the Kumba group of *Solanum aethiopicum* L.**

[Sources: Porcher, 2009 (A, B, C, E, F); AVRDC-Mali (D)]

**Figure 5: Fruit and leaf aspects of the Shum group**

[Sources: Schippers R. (left); ECPGR, 2009 (right)]

**Figure 6: Views of different varieties of the Aculeatum group and plant aspect**

[Sources: Porcher, 2009 (left and top right); ECPGR (bottom right)]

Figure 6 presents examples of varieties of this group with slightly flattened to round fruits. Other genotypes are very prickly and have dark flattened and ribbed fruits resembling those of the Kumba group, with smaller size.

***Solanum macrocarpon* L.:**

*S. macrocarpon* can easily be distinguished from *S. aethiopicum* by its large hairless leaves, stems and its long calyx persisting after formation of its smooth green or yellow fruits.

*S. macrocarpon* is a popular traditional vegetable in west and central Africa, also very common in Asia and tropical America. Spiny wild forms are found throughout the humid parts of tropical Africa, occasionally collected as vegetables. It has several names including African eggplant, or *Gboma* eggplant or just *Gboma* (the name of a Liberian village). The leafy varieties are common throughout west and central Africa, while the fruit types are mainly restricted to the humid coastal areas of west Africa. Some varieties have both edible leaves and fruits. *S. macrocarpon* is also widespread in east and southern Africa and in South America. The following four varietal groups of this species recognized by Bukenya and Carasco (1994) have been reported by Porcher (2009), namely Mukono, Nabingo, semi-wild and Uganda group (See figure 7).

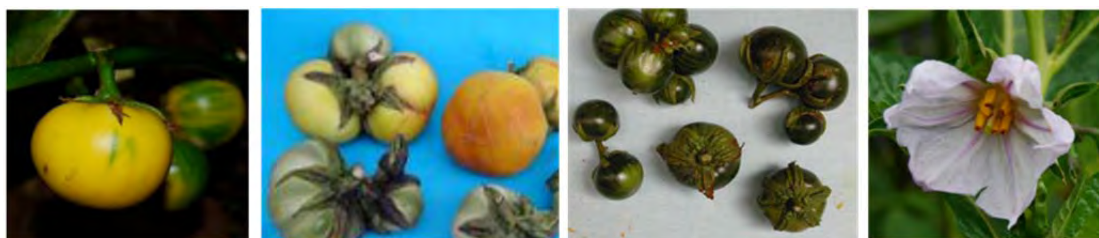

**Figure 7: Pictures of different varieties of *S. macrocarpon* and flower aspect**

[Sources: Porcher, 2009 (A & B); ECPGR, 2009 (B & C)]

## FLORAL MORPHOLOGY AND BIOLOGY

Description by previous research work (Seck, 1986) reported that the flowers of *S. aethiopicum*, like those of other *Solanum* species, are bisexual, either solitary, in inflorescences with short cymes or trusses. Solitary flowers and cymes are mostly found in the Kumba group, whereas trusses are most common in the Gilo and Aculeatum subspecies, and linked to fruit number and size. The short stamens bearing yellow pore dehiscence anthers at anthesis stage form a cone surrounding the style bearing a stigma placed beneath, beyond or at the same level as the pores. The last type referred to as peristyled flowers, has been observed to favour self-pollination. Style heteromorphism observed in *S. melongena* seems to be linked to the sterility of short styled flowers, whereas the Kumba group only bears perityled flowers (See figures 1 and 2, annex 2).

In the Kumba group, solitary flowers and cymes have been observed to be fertile which may be linked to flower morphology. In *S. aethiopicum* and *S. macrocarpon*, plants generally start flowering about 70 days after sowing or 35 to 40 days after transplanting. Stigma receptivity has been observed to start on the day before anthesis whereas pollen viability occurs on the day of anthesis or 1 day later and can remain so for up to 2 days later. Male sterility, which is rather scarce in *Solanum melongena*, has been reported to be caused by low temperatures or by treatment with growth regulators (Choudhury and George, 1962). African eggplants have been observed to be partially autogamous (natural cross pollination estimated to about 20%) (personal observation). In tropical areas, insect pollination is generally favoured by bees (e.g.: *Exomalopsis* spp.). Unlike *S. melongena* for which insect pollination is reported to represent 60 to 70%, *S. aethiopicum* has been observed to produce fruits and seeds under isolated conditions.

## GERMPLASM AND GENETIC DIVERSITY

In African eggplants, genetic diversity seems to be very important mainly in *S. aethiopicum* L., due to its diverse groups including different varieties each. This seems to also apply to *S. macrocarpon* reported to comprise several varietal groups. This diversity is mainly linked to phenotypic differences (e.g.: stem, leaf and flowers colour, fruit shape and size at different stages, flower size, leaf pubescence and prickliness, etc.). Desirable characters [e.g.: yield,

yield components, fruit quality, mite resistance linked to leaf pubescence (antixenosis), etc.] can easily be transferred from one group to another due to absence of hybridization barriers (intraspecific combinations). Genotypic variation is also important at interspecific level. In terms of breeding potentials, African eggplants are also reported to possess useful characters for varietal improvement of non tuberous species like *S. melongena* [e.g.: diverse agronomic traits, resistance of *S. aethiopicum* to *Pseudomonas solanacearum*, *Fusarium oxysporum* f. sp. *melongenae*; resistance of *S. macrocarpon* to spider mites and the fruit borer (*L. orbonalis*), etc.].

Efforts have been made by research institutes in terms of germplasm management (collection of local accessions and conservation). However, due to lack or absence of sustainable means, PGR[2] ex situ conservation is made difficult. As a result, the major part of genetic diversity seems to be under farmers' custody mainly through traditional (in situ and ex situ) conservation methods of cultivars endemic in the respective production areas. In Senegal, local varieties of *S. aethiopicum* (Kumba) and to a lesser extent of *S. macrocarpon* are easily recognisable based on fruit size, colour, shape, etc. They are jealously conserved by farmers and nearly confined in their respective areas of origin or diversity (e.g.: *Keur Mbir Ndao* originates from a village of the same name; *Blanc de Nioro*, a white variety is from Nioro, etc.).

## BREEDING

### Breeding goals

In Africa, most breeding programmes are focused on developing commercial open pollinated varieties based on yield, yield components and fruit characteristics (colour, size, taste, etc.); more specifically, breeding activities in Senegal have been mainly focused on resistance to mites, to *Stemphylium/Alternaria solani* and to nematodes (Seck, 1986, 1997). Other research work reported by Sekara et al. (2007) was aimed at exploiting intraspecific hybrid combinations of *S. aethiopicum* for high yielding. In terms of actual breeding work, a lot of cross attempts have been reported though little research seems to have been carried out regarding key aspects like inheritance, heterosis, insect resistance, etc.

### Intra and interspecific hybridization

Successful crosses of different varieties of (different groups of) *S. aethiopicum* have been reported with a few examples as follows:

$F_1$ hybrids of *S. aethiopicum* obtained by Omidiji (1979) and Carvalho and Ribeiro (2002), cited by Sekara et al. (2007);

Hybrids of different groups of *S. aethiopicum* (Kumba x Gilo; Kumba x Aculeatum) (Seck, 1984);

Diallel crosses and combing ability studies on Brasilian varieties (Carvalho and Ribeiro, 2002, cited by Sekara et al., 2007);

Several interspecific combinations have also been attempted by different authors, between *S. aethiopicum*, *S. macrocarpon* and *S. melongena* for improvement purposes. Part of these attempts has been successful mainly through the use of special techniques. A few examples of reported failures relate to combinations of different *S. aethiopicum* groups with wild species (e.g.: *S. sisymbrifolium*, *S. torvum*) and with *S. macrocarpon.* As to successful crosses, they relate to combinations of different groups of *S. aethiopicum* with *S. melongena*, *S.*

[2] PGR: Plant genetic resources

*macrocarpon* and *S. anguivi.* Annex 3 presents further details on successful crosses and failures.

**Breeding procedures**

Breeding methods are selected based on species involved and objectives. Annex 4 summarises the main steps of a breeding program starting from problem identification to variety release through breeding goals, genetic variability assessment, selection of breeding methods and cycles, etc. To successfully conduct a breeding program, a minimum knowledge of the plant species involved (floral biology, inheritance of the key attributes, cultural practices, plant lifecycles, etc.) and of the appropriate breeding techniques is needed.

As to inheritance in *S. aethiopicum*, useful information has resulted from research work in Senegal mainly focused on yield, fruit quality, mite resistance, etc. (Seck, 2000). Part of these findings are summarised below:

**Leaf hairiness (H;h) and prickliness (S;s):** Analysed data collected on $F_2$ plants of reciprocal crosses between Kumba and Aculeatum groups showed dominance of both attributes with gene combinations through proportions significantly close to 9/16 (genotypes: HHSS, HHSs, HhSS, HhSs), 3/16 (HHss, Hhss), 3/16 (hhSS, hhSs) and 1/16 (hhss) [computed chi-square value = 3.95 < tabulated value = 7.8 (7 dof)].

**Fruit shape:** $F_2$ plants from 2 crosses with Kumba (flattened) and Gilo (long fruited) resulted in phenotypic proportions statistically identical to those expected from a Mendelian intermediate character: 1/4 long homozygous, 1/2 thick flattened heterozygous and 1/4 flattened homozygous [chi-square values = 1.7 and 1.32, lower than the theoretical value (6.0)].

**Other attributes:** Fruit green colour, plant anthocyanins and truss inflorescence appeared dominant and may be of Mendelian inheritance, with respective proportions close to 3/4 and 1/4 for $F_2$ plants.

Additional information is provided by the same source on correlation studies in *Solanum aethiopicum* (crosses between different groups) through the examples presented in table 3.

**Table 3: Examples of parameters correlated in African eggplants**

(Source: Seck, 2000)

| Crosses | Parameters correlated | | r values | Signif.[3] | Comments |
|---|---|---|---|---|---|
| | Parameter 1 | Parameter 2 | | | |
| Aculeatum X Kumba | Flower number per inflorescence | Fruit number per cluster | +0.83 (47 dof[4]) | 1% | Positive correlation; This gives evidence of flower fertility of cymes and trusses |
| Gilo X Kumba | Flower number per inflorescence | Fruit number per cluster | +0.73 (80 dof) | 1% | |

[3] Signif.: significance

[4] Dof: Degrees of freedom

| Aculeatum X Kumba | Fruit number per cluster | Fruit weight (g) | -0.43 (25 dof) | 5% | Negative correlation; Fruits smaller on cymes than in solitary flowers and on short cymes than on trusses |
|---|---|---|---|---|---|
| Gilo X Kumba | Fruit number per cluster | Fruit weight (g) | +0.25 (79 dof) | 5% | |

Examples of breeding methods successfully used on African eggplants considered partially self-pollinated (Seck, 1998, 2000) are summarised as follows:

**Positive and mass selection:** As part of *conservative breeding*, these methods are used either to separate distinct lines within the same plant population (selfing), or to purify a heterogeneous variety (negative selection through gradual suppression of off-to-type plants). A number of varieties belonging to different groups of *S. aethiopicum* and *S. macrocarpon* have been improved through these methods [e.g.: *Soxna*, *Ngalam*, *Ngoyo* (Kumba), *Ndrowa Issia* (Gilo), *Nen u baa* (*S. macrocarpon*), etc.] (See examples in figure 8).

**Figure 8: Ngalam (Senegal, left) and Ngoyo (Mali, right) from conservative selection**

(Source: Technisem)

**Pedigree selection** is a *creative breeding* method used when a limited number of desirable characters need to be transferred from 2 parents in a new open pollinated variety. The parental lines are hybridised to obtain the $F_1$ which will be self-pollinated to produce $F_2$ plants to be studied and selected individually to obtain $F_3$ families. Then all selected lines are selfed from $F_3$ to $F_n$ to obtain stable lines. From experience, if selfings are carried out on a regular basis, the first homozygous lines will appear at $F_4$ stage (2-3 generations/years, 2-3 years); examples can be given on mite resistance through crosses between Kumba (*Soxna*) and other groups like Aculeatum and Gilo which generated new varieties namely *Line 10* (Gilo x Kumba) and *Line 18* (Kumba x Aculeatum) (Seck, 1986) (See figure 9).

**Figure 9: Tetranychids on 2 $F_2$ plants of the same cross (Gilo x Kumba): A: hairless leaves (defoliated) and B: hairy leaves (resistant); C: OP Line 10, mite resistant (Gilo x Kumba) (Source: AVRDC, Mali)**

(Source: Seck, 1986)

Hybrid breeding

This method is appropriate for simply inherited dominant genes and self-pollinated species; it has been reportedly used through a diallel test by Carvalho and Ribeiro (2002) on Brasilian varieties of *S. aethiopicum*, and by Seck (2000) on okra.

The breeding procedure can be briefly explained as follows:

A number of n stable parents (OP varieties) are selected and inbred;

Combining ability test is performed through as many combinations of parental lines 2 by 2 as possible, not including reciprocal crosses (total hybrid number expected: $N = n(n-1)/2$), (e.g.: 45 hybrid combinations expected from 10 parental lines);

All hybrid combinations are then tested compared to their respective parents based on the calculated values of heterosis or heterobeltiosis through yield or yield components.

The best parents (with good specific and general combining ability) are identified for future hybrid production; then, the best combinations are selected for seed production and further yield trials and release to farmers.

Backcrossing

This method is another variant of *creative breeding* which preferably applies to specific cases of self-pollinating species and a very limited number of simple inheritance genes (Seck, 2000). It has been proposed to improve *Soxna* and *Keur Mbir Ndao* (2 Senegalese Kumba group varieties) for mite resistance and suppression of seed embryo dormancy (Seck and Sow, 1993; Seck, 2000[5]). As a general rule, this method fits in cases whereby a good variety referred to as the *recurrent parent* (preferably homozygous) needs to be improved through transfer of one to a few dominant genes. The required variability is expected from the *donor* parent. Practically, the $F_1$ hybrid is crossed with the recurrent parent to obtain the first backcross generation ($BC_1$); then selected plants bearing the transferred attribute(s) in addition to the positive characters of the recurrent parent are crossed again with the latter ($BC_2$); the process goes on as many times as needed up to $BC_n$ to obtain stable lines (homozygous for characters considered).

## CROPPING SYSTEMS

African eggplant is a key component of traditional small-scale cropping systems in sub-Saharan Africa. In some countries, it is gradually being considered as an important exotic product for export. In Senegal, *S. aethiopicum* (Kumba) has been cited by producers among the 8 major vegetable species including tomatoes, cabbage, onions, Irish potatoes, European eggplants and okra (Seck, 2002). However, it has still received little consideration in national policies in Africa as compared to temperate climate items. As tropical crops, African eggplants are grown all year round with a number of constraints including the following:

Quality seed supply

Seed germination issues in cool season

Poor control of pests and diseases

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[5] Seck, A. 2000. Advances in seed research on embryo dormancy of African eggplant (*Solanum aethiopicum* L., group Kumba) (unpublished)

Unaffordable production factors (fertilisers, pesticides)

Drudgery in water lifting and distribution mainly manual,

Etc.

Sowing can be done at any time of the year for full and off-season production, though in the humid parts of Africa, crops are mostly rainfed. Plant spacing is variable, simple row planting design being common in traditional systems with about 0.8 to 1 m apart, inclusive of footpaths or not (10,000 to over 15,600 plants/ha). Trained farmers applying recommended packages including plant densities (between 20,000 to 27000 plants/ha) can increase their yields. Flowering, pollination and fruit formation generally take place about a month and half after transplanting.

Organic production mainly focused on the use of large quantities of farm manure (50 to 80 tons/$m^2$) associated to biopesticides and botanicals, is practised by a limited number of producers mainly for export purposes. This obviously leads to improved fruit quality, though yields are often lower as compared to conventional intensive systems.

**Cultivar selection and nursery management**

***Planting material***

*Varieties and cultivars of African eggplants*

African eggplants are very diverse in terms of varieties. For the 3 species, the majority of cultivars grown mainly originate from natural and farmers' selection, and more scarcely from conventional breeding. However, varieties which have survived from any of these selection processes mainly local ones endemic in production areas are most appreciated by consumers. For African eggplants, the most common selection criteria taking consumers' needs into account include the following:

- Leaf aspect (leaf size, thickness, presence or absence of hairs and prickles, etc.)
- Fruit colour (at consumption and physiological maturity stages)
- Fruit size
- Flesh taste (bitter to sweet)
- Etc.

However, farmers' selection criteria focused on agronomic criteria are also important to be considered (e.g.: earliness, leaf and fruit yield, "easiness to produce" linked to biotic and abiotic stress tolerance, etc.). However, local varieties are well known for their lack of uniformity. Figure 10 shows 3 different plants in respect aspect of the vegetative parts, identified from the same Kumba group population in The Gambia.

**Figure 10: Three different varietal types within the same population (Souareh kunda, N. Bank, The Gambia) based on leaf aspect: A: hairy green plant; B: true-to-type plant; C: natural sterile hybrid (*S. aethiopicum* x *S. melongena*?); D: 2 plants with different stem colours in Bajana (W. Region).**

(Source: Seck, 2009, unpublished)

Varietal heterogeneity is also reflected on plant reproductive parts (e.g: fruit size, colour, etc.). Figure 11 below shows 5 different fruit types of the same population.

**Figure 11: Different fruit sizes and colour of the same population in Bajana (W. Region)**

(Source: Seck, 2009, unpublished)

Additional selection criteria based on export requirements will focus on fruit attractiveness, homogeneity in size and colour, etc. This seems to justify hybrid breeding aimed at exploiting the positive traits of $F_1$'s.

Appellations of varieties are much diversified as most cultivar names are often given by farmers in their own language. In addition, a number of varieties have women's names. Sekara et al. (2007) in their review of African eggplant names have mentioned several examples mainly focused on scarlet and Gboma eggplants. As well, a large number of cultivars are listed for each species by the ECPGR. A few examples are given below:

- *S. aethiopicum*: *Tenguru White* (Gilo, east Africa), *Soxna* and *Ngalam* (Senegal), *Ngoyo* (Mali) (Kumba), etc. As it relates to the Aculeatum group neglected from a culinary point of view, and very common in Japan, variety Lizuka is mainly used as root stocks. Other cultivars reported by Porcher (2009) and not yet confirmed as varieties of the Aculeatum group are *Tingua Verde Claro* and *Red China*.
- *S. macrocarpon*: It is morphologically less diverse than *S. aethiopicum*. Varieties may relate to the 4 types mentioned above and to use (leaf and/or fruits). Examples of common varieties in Ghana are *Gboma* (leaf and fruit), *Bui* (fruit) and *Kade* (leaf). Variety *Nen u baa* has been developed in the 80's in Senegal where the species is less popular as compared to *S. aethiopicum*. In Togo, an example of the cultivars grown is *Agbitsa*.
- *S. anguivi*: As shown in figure 2, varieties which are all of small fruit size, mainly differ in terms of shape, colour and taste and most of them are bitter. In Cote d'Ivoire, the common striped varieties known for their bitterness include the *Gangnan* type. Other varieties are natural crosses of Gilo group and *S. anguivi* referred to as types of the "Gilo anguivi group".

*Seeds and seed production*

The multiplication procedures used for *S. aethiopicum* L., subsp. *Kumba* also applicable to the other groups are summarised in table 4 below (Seck, 2001). In summary, 3 months are needed in average after transplanting for the crop to reach full fruit maturity necessary to enable seed development, germination and plant emergence (maximum vigour). Harvest and post-harvest will take over a month and half with expected average seed yield about 300 kg/ha.

Seed production cost estimates carried out by the same author, based on a 1,000 $m^2$, an

average yield of 300 kg/ha and a selling price of CFA F35,000 (US$72[6]) resulted in an average cost of CFA F10,114/kg (US$20.8). The highest expenses in % and in a decreasing order are irrigation (35.4%), labour (33.9%) and inputs (24.3%) (See details in table 5).

Fresh seeds of African eggplants can have different behaviours after harvest. In particular, embryo dormancy is a key issue in most varieties of the Kumba group, consisting of absence of (or limited) germination of new seeds. *Ngalam* of Technisem (France) is a variety selected for absence of dormancy (Seck, 1993); seeds of dormant varieties need artificial breaking by soaking seeds in a solution of gibberellic acid ($GA_3$, 500 ppm; 24 hours) for immediate germination. Further investigations revealed that embryo dormancy is influenced to a significant extent by low temperatures during pollination and fertilisation; in addition, hybrids between dormant and non dormant seeds were non dormant (Seck, 2000[7], unpublished research). Another solution is natural breaking through storage for 4-5 months, which is possible if required temperature and relative humidity conditions are fulfilled. At local level, small scale farmers have their own way of storing seeds consisting of leaving them within the berries scattered on their house roofs, for extraction a few months later.

**Table 4: Summary of seed production of African eggplants**

(Source: Seck, 2001)

<table>
<tr><th>Steps</th><th colspan="6">Details</th></tr>
<tr><td>Varieties/cultivars</td><td colspan="6">Keur Mbir Ndao, Soxna, Ngalam, L10, L18, etc.</td></tr>
<tr><td>Site selection/isolation/ densities</td><td colspan="6">Isolation distance: 200 m; recommended previous crops: amaranth, cabbage, groundnut, onion, etc.; 20,000 plants/ha in single rows.</td></tr>
<tr><td>Irrigation/fertilisation</td><td colspan="6">9 mm/day in average daily; fertilisers: 150 (N)-150 ($P_2O_5$)-200 ($K_2O$) + 20 t of manure/ha.</td></tr>
<tr><td>Pest control/care</td><td colspan="6">In arid areas of west Africa preventive and curative control is needed for mites (resistance, chemicals), caterpillars including flower bud borer (contact and systemic pesticides), powdery mildew, Stemphylium/Alternaria complex (fungicides), and nematodes (Meloidogyne spp.).<br>Care: regular weeding.</td></tr>
<tr><td>Rouging procedures</td><td colspan="6">Characters to be controlled: 1. Vegetative growth (before flowering): leaf shape, colour, hairiness and prickliness; 2. Full flowering stage: date to 50% flowering, flower size and colour; 3. Fruit formation: fruit shape, size and colour at consumption and full maturity stages; seed borne diseases, etc.</td></tr>
<tr><td>Harvest/post-harvest</td><td colspan="6">Full maturity occurs about 90 days after transplanting (orange to red fruit colour, fruit softening); harvest duration: 40 days (total lifecycle = 130 days). Select best fruits for seed extraction. Fruit yield: 30 t/ha; seed yield: 200-400 kg/ha (10 g of seed/kg of fruit).<br>Seed extraction to be carried out by hand or mechanically; seed to be dried naturally or artificially at temperatures between 35 and 45°C to inversely vary with seed moisture content. Seeds to be packed in airtight containers and stored under required conditions (e.g.: 10°C, 50% relative humidity).</td></tr>
<tr><td rowspan="3">Quality control<br>(indicative references)</td><td colspan="2">Moisture content</td><td colspan="2">Germination</td><td colspan="2">Purity</td></tr>
<tr><td>G[8]</td><td>R[9]</td><td>G</td><td>R</td><td>G</td><td>R</td></tr>
<tr><td>7%</td><td>7%</td><td>75%</td><td>75%</td><td>98%</td><td>98%</td></tr>
</table>

[6] US $1 = CFA F486 (West Africa, October 2009)

[7] Seck, 2000 (unpublished). Advances in seed research on embryo dormancy in African eggplant (*Solanum aethiopicum* L., ssp. *Kumba*)

[8] G: notation for foundation seed class

[9] R: notation for commercial or standard seed class

**Table 5: Details of seed production cost estimates**

(Source: Seck, 2001)

| Items | Quantities/Values | % |
|---|---|---|
| Area cultivated ($m^2$) | 1,000 | - |
| Production (kg) | 30 | - |
| Selling price (US $/kg) | 72 | - |
| **Total turnover** | **2160.5** | - |
| **Expenses (US $)** | | |
| Inputs | 151.5 | 24.3 |
| Labour | 211.6 | 33.9 |
| Irrigation | 220.9 | 35.4 |
| Depreciation | 29.1 | 4.6 |
| Miscellaneous | 11.1 | 1.8 |
| **Total expenses** | **624.3** | **100** |
| **Production costs** | **20.8** | -- |
| **Net margin** | **1536.2** | -- |

*Nursery management*

Traditional nursery management is still practised by farmers through beds not always well demarcated and prepared, etc., whereby seeds are unevenly broadcast. Recommended seedling production (Seck, 2001, 2003, 2008) is based on sowing in nursery beds or on trays for transplanting after 5-6 weeks (beds) vs. 3 to 4 (trays). Traditional sowing is done on 1 meter wide beds, previously prepared (2 $kg/m^2$ of manure and 40 g of compound fertiliser). Seeds are put in shallow transversal furrows with 20 cm spacing between rows, and watering and care are ensured on a regular basis. Seed rate depending on plant spacings and net density, will be estimated based on the following formulas aimed at optimising seed rates in order to reduce seed wastages (Seck, 2008):

- *Plant net density*, $D_n = S_n .10^4 / (s_n . S_b)$ whereby $10^4$ represents 1 ha (10,000 $m^2$), $S_n$ and $S_g$ respectively net and gross areas cultivated (in $m^2$), and $s_n$ the net area occupied by 1 plant;
- *Seed rate in g/ha*, $Q = (D_n \times 2) / n$ whereby $D_n$ is the net density and $n$ the number of seeds contained in 1 gram.

Practically in a double row design, if 0.5 m is adopted as plant and row spacing and 1 m between double rows, plant density will be up to 26,667 plants/ha; this figure will be reduced to 20,000 plants/ha in a simple row design with the same spacings. Respective seed rates will be up to 178 and 133 g/ha. Farmers' transplanting design is generally very dense (1.5 to 2 folds as compared to recommended practices). Figure sowing consists of putting 1 seed in each hole filled with nursery compost for transplanting 3 weeks later. This method requires less seeds (80-106 g/ha) and is very effective in terms of seed germination, seedling growth and plant recovery after transplanting. However, it requires a minimum equipments and accessories (insect proof structure, trays, nursery compost, etc.). Figure 12 presents views of a traditional nursery with broadcast seeds and of fully developed plants of bitter tomato (Kumba group).

**Figure 12: Traditional nursery S. kunda (N. Bank) and plot of African eggplants in Ndemban (W. Region)**

(Source: Seck, 2009, unpublished)

## SOIL FERTILITY AND PLANT NUTRITION

In small-scale farmers' traditional cropping systems, soils are generally poor and fertiliser application not systematically done as a result of availability and affordability issues. A number of surveys in different production areas of Senegal (Seck, 2002, a, b) have shown that in the northern part, only 26% of farmers use organic matter vs. 100% for compound fertilisers (available due to industrial tomato production); as to coastal areas (Niayes), 92% of farmers apply manure to their crops but at low rates (13 t/ha in average). In addition, chemical fertiliser is only used where and when it is available. Accordingly, in any case, the total mineral supplies to crops (N + $P_2O_5$ + $K_2O$) are always lower than recommended quantities, and generally imbalanced with excess of nitrogen due to inappropriate use of urea.

In intensive crops, the recommended mineral bill for African eggplant is up to 100 (kg of N) – 100 ($P_2O_5$) – 200 ($K_2O$) through the following plan:

- Direct application (conventional fertilisers):
    - Basal application: 400 kg of 10-10-20 + 20 t of manure per ha (to be incorporated);
    - Top dressings: 3 applications of 10-10-20 (200 kg/ha): 20, 40 and 60 days after transplanting. In case of availability issues, quantities of NPK needed can be supplied with any compound fertiliser (e.g.: 15-15-15, etc.) to be complemented by simple or binary ones.
- Fertigation (drip irrigation + soluble fertilisers): 1 to 3 applications of the starter (growth fertiliser) a week until early fruit formation, whereby the development fertiliser will be applied. To reduce fertiliser costs, 1/3 of the recommended bill can be supplied through compound fertilisers.

As it relates to leaf production, a balanced ratio between nitrogen and potassium supplies (close to 1:1) is needed to maximise yield.

## IRRIGATION AND WATER MANAGEMENT

As stated above, traditional cropping systems are generally rain fed, but where water is available, manual lifting and distribution which is time consuming represents the major irrigation method in dry season.

Manual water supply has been observed to take 65% of working time (Seck, 1999), which is a constraint to local production in arid and semi-arid areas of Africa.

*Quality of irrigation water*: African eggplant is considered moderately sensitive to salinity and tolerant to acidity (optimum pH of soil solution: slightly acidic).

*Irrigation needs*: Crop evapotranspiration ($ET_c$) based on work by Doorenbos and Pruitt (1975) is estimated for the Senegalese climate up to an average of 4.1 mm a day. Based on a total crop lifecycle of 130 days exclusive of nursery duration, this results in total crop intrinsic water needs up to 5,330 $m^3$ ($ET_c$). As a result, total irrigation needs linked to irrigation methods through their respective efficiency, has been estimated to 11,840 (surface irrigation), 8880 (sprinklers) and 5610 $m^3$ (drip irrigation). Practical details of water supply proposed according to plant growth stages are presented in table 6 below.

**Table 6: Estimated water needs for African eggplant as linked to irrigation systems**

(Source: Seck, 2003)

| **Irrigation systems** | **Phase 1 (1$^{st}$ month) (l/m²/day)** | **Phase 2 (2$^{nd}$ month) (l/m²/day)** | **Phase 3 (3$^{rd}$ month) (l/m²/day)** | **Total supply ($m^3$/ha)** |
|---|---|---|---|---|
| Surface irrigation (Efficiency = 45%) | 6,4 | 9,1 | 11,8 | 11840 |
| Sprinkler irrigation (Efficiency = 65%) | 4,8 | 6,8 | 8,9 | 8880 |
| Drip irrigation (Efficiency = 95%) | 3 | 4,3 | 5,6 | 5610 |

## INTEGRATED PEST MANAGEMENT

In the arid and semi-arid areas of west Africa, African eggplants crops generally based on hairless leaved varieties face a number of pests and diseases of which mites are the main ones. Two main families are involved being the *Tetranychidae* and the *Tarsonemidae*:

- *Tetranychid mites* are hardly visible and cause foliage yellowing and drying. The two-spotted spider mite (*Tetranychus urticae* Koch) is a common representative on African eggplants. Adults are about half a mm long (males being slightly smaller); the larvae are of pale yellow to green colour, whereas adults are slightly brown, with two dark spots on the body. The biology of tetranychid mites is favoured by low moisture conditions. Larvae and adults shelter at the leaf underside where the latter lay eggs and produce intensive webbing, causing leaves to speckle, turn yellow, or deform. Finally, plants may defoliate and die (See figure 13). Two-spotted mites are known to attack all hairless leaved varieties except *S. macrocarpon* observed and reported to be resistant (Schaff et al., 1982; Seck, 1984).
- *Tarsonemid mites* constitute a second major pest in African eggplants, with smaller size making them invisible to the naked eye (0.2 mm). *Polyphagotarsonemus latus* Bank referred to as the broad mite, is reported to be the most common species on eggplants, peppers, Irish potatoes, beans, etc. in Africa. Larvae and adults of this family are shiny, pale yellow and transparent and mainly occur in the cold season. In African eggplants, they prefer young leaves and cause browning of the leaf area between veins, leaf shrinking, curling downward and narrowing, finally drying and death. Intensive attacks can also cause damage on flowers and fruits (See figure 14).

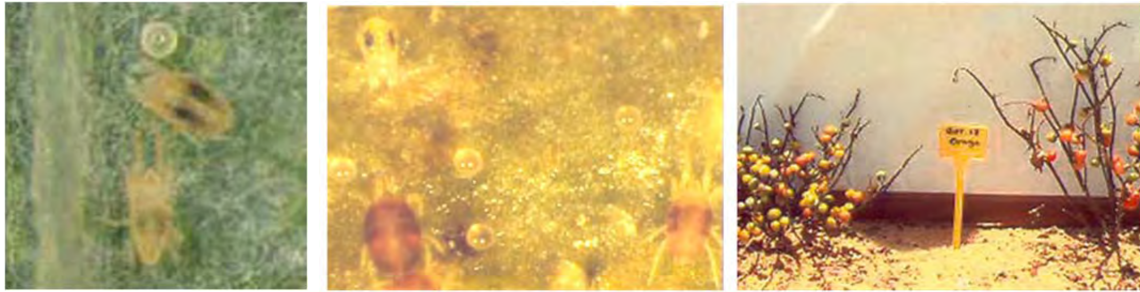


**Figure 13: Aspect of Tetranychid mite (adults, larvae and eggs) and damage on the Shum group variety from DRC[10]**

(Sources: Cranshaw and Sclar, 2011; Seck, 1986)

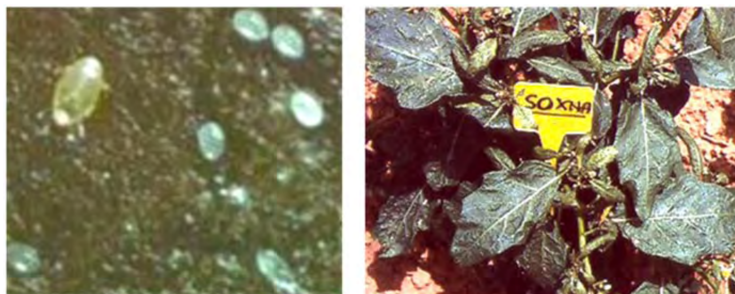



**Figure 14: Left: Aspect of *Tarsonemidae* (adults and larvae); Right: damage on Soxna (Kumba group)**

(Source: A: Anonymous, 2009; B: Seck, 1986)

Preventive (and if needed curative) IPM control measures will consist of associating different methods aimed at strengthening the on-going natural control by predators and parasitoids:

- *Chemical control* (to be the last resort) consists of using broad spectrum insecticides [Dimethoate to be handled with care to avoid effect on predators (FAO, 1988)] and fungicides (sulphur) or in case of severe attacks, specific miticides like Dicofol;
- *Varietal resistance* (e.g.: hairy leaved cultivars, improved varieties like Line 10, etc.);
- *Cultural control*: where possible, sprinkler irrigation or the use of hose pipe can contribute to reduce the mite populations;
- *Organic control* through the use of botanicals [e.g.: Neem (*Azadirachta indica*) products (leaves or kernel extracts, oil, etc.)];

Under controlled conditions (greenhouses) mite predators belonging to the *Phytoseiidae* family have been reported effective on both *Tetranychus urticae* and *Polyphagotarsonemus latus* in *Solanum macrocarpon* crops (Adango et al., 2007). Figure 15 shows pictures of 2 different types of mite predators.

[10] DRC: Democratic Republic of Congo

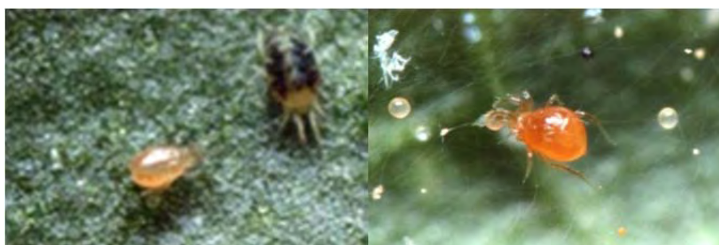


**Figure 15: Views of 2 different mite predators approaching a two-spotted spider mite or eggs**

(Source: Certis, 2009)

Other pests and diseases of importance under growing conditions of arid and semi-arid zones of sub-Saharan Africa need to be controlled (See examples as follows):

- *Root knot nematodes*: African eggplants, mainly *Solanum aethiopicum* group Kumba is known to be highly susceptible to eelworms (*Meloidogyne* spp.). As it relates to genetic control, screenings for resistance of 8 accessions of *S. aethiopicum* (Gilo, Kumba and Aculeatum) and of *S. macrocarpon* by Demaeyer (1985) in Senegal resulted in high infestation rates: average rate = 69.3%, maximum and minimum: 90% (Gilo group) and 55% (Aculeatum) as compared to Soxna (Kumba) with 67%. Currently, chemical control is expensive and has not guaranteed 100% reproducible results. As a result, cultural control through crop rotation appears to be the most reliable method. In particular, in Senegal and the Gambia (west Africa), groundnuts planted as a previous crop in heavily infested plots, has proven very effective as a trap crop (personal observation).
- *Flower bud borers*: In general, caterpillars (*Lepidoptera*) can be a problem when African eggplants are grown close to other old solanaceous crops. In particular, *Scrobipalpa* sp. previously observed in tomatoes in Senegal, now referred to as the flower bud borer, has become a most dangerous pest of *jaxatu* crops. Heavy infestations can cause more than 50% yield losses. The adult lays eggs in young flower buds and after hatching, the caterpillar stays inside the ovary where it spends all its development stages before leaving throughout a big hole; as a result, the empty ovary aborts and drops. This makes the pest nearly invisible and unknown by farmers who can only see flowers. The best control measure recorded is the use of systemic insecticides (e.g.: Acephate), or prevention with Bt[11] based biopesticides like Biobit (See figure 16).

**Figure 16: Views of damaged flower buds by *Scrobipalpa* sp. as compared to normal flowers**

(Source: A. Seck, unpublished)

[11] Bt: *Bacillus thuringiensis*

- *Aphids*: In west Africa, *Aphis gossypii* is one of the major species reported in European and African eggplants. They are tiny pests (1.5-2.5 mm long) and both adults and nymphs attack crops as sucking pests. Feeding results in various symptoms and damages: leaf rolling, deformation, curling, bending, etc. Heavy infestations can also damage flowers and fruits. The sugary honeydew secreted by aphids on leaves and other plant parts is known to facilitate the development of a fungus (sooty mould); heavy attacks weaken plants and reduce photosynthesis, plant growth and yield. IPM control relates to the use of different and complementary means with examples as follows:
    - *Biopesticides and physical methods*: Neem extracts recommended for early infestation stages. Repeated spraying is necessary and there are risks of phytotoxicity, but no significant effect on natural enemies. As well botanicals like chilli pepper solution associated to soap. Wood ash already used by local farmers can be effective when evenly dusted or sprayed with sap on the lower leaf surface.
    - *Chemical and biological controls*: Some insecticides like acephate, dimethoate, malathion, endosulfan, etc., have resulted in effective control. Aphids are attacked by a number of parasites and predators. It is recommended to use selective chemicals to preserve natural enemies (e.g.: repeated use of pyrethroids may cause an outbreak of aphids).

Figure 17 shows pictures of aphid populations on African eggplant and leaf curl symptoms.

**Figure 17: Views of a damaged leaf and of aphid colonies on African eggplants in The Gambia**

(Source: A. Seck, unpublished)

- *Stemphylium solani:*This fungus is very common on the Kumba group varieties. It is mainly characterised by many small brown round to angular spots of 2-4 mm with grey centres on the old leaves which turn yellow and prematurely drop. Under hot and humid conditions, the infection extends to the younger leaves. The fungus has been observed to be associated with *Alternaria solani* which does not show specific symptoms (Demaeyer, 1985). Screenings for resistance of 10 accessions including different groups of *S. aethiopicum* (Gilo, Kumba and Aculeatum) and of *S. macrocarpon* by the same author revealed an average infection rate of 16%, extreme values being 34% (*S. macrocarpon*) and 0% (Gilo) as compared to variety Soxna (Kumba) with 32%. Preventive (or curative) control is possible by spraying the upper leaf area with Manebe (See figure 18).

**Figure 18: Aspect of *Stemphylium* symptoms on Soxna (*S. aethiopicum* L., group Kumba)**

(Source: FAO, 1988)

- *Leaf miners*: *Liriomyza trifolii* is the major species in west Africa; it is a diptera which can reach damaging levels quite rapidly if certain disruptive insecticides (e.g.: pyrethroids) are repeatedly used. *L. trifolii* is common on a number of vegetable crops including scarlet eggplants, which explains its year round presence in small gardening. It develops through a 4-stage cycle (eggs → larvae → pupae → adult). The adult lays eggs in leaves and the larvae feed and circulate between leaf surfaces, through "mines". Heavily mined leaves have large whitish blotches and drop prematurely. Foliage punctures by the adults contribute to global damage but are less harmful compared to the mining activity by larvae. When mature, the larvae leave the mines through an external opening on the leaf surface, and drop to the ground to enter the pupae stage. The life cycle takes only 2 weeks in warm weather with 7 to 10 generations a year. At optimal temperatures (30°C), the vegetable leafminer completes its development from the egg to adult stage in about 15 days (See figure 19).

**Control measures**

- Cultural control: Check transplants before planting and destroy infested seedlings, use an insect proof greenhouse, shelter, or mosquito net ("sankey") to avoid infestation.
- Chemical measures: Leafminers are resistant to a wide range of pesticides. Cyromazine has given good results in Senegal and The Gambia; if possible it can be alternated with Abemectin or Spinosad; in addition, it is recommended to avoid abusive use of pyrethroids (risk of resistance).
- Biological and organic control: leafminers are attacked by a number of parasitoids mainly *Hymenoptera*. Biological control as a component of IPM will mostly consist of safeguarding natural enemies through the use of selective insecticides, and by avoiding abusive use of insecticides.

**Figure 19: Aspect of leafminer adult and larvae**

(Source: Capinera, 2009)

## HARVEST AND POST-HARVEST

Fruit harvest at consumption stage is due about 2 and half to 3 months after planting, whereas physiologically mature fruits also consumed in some countries occur one month later. The total lifecycle estimated for consumption maturity stage (130 days in average) is variable according to species, cultivars and cropping conditions.

Fruit yield is variable going for *S. aethiopicum* from less that 10 to over 30 t/ha, with potential yield of about 40 tons in intensified crops (e.g.: high rainfalls and drip irrigation, appropriate fertiliser application and pest control, etc.). Yield potentials for *S. macrocarpon* and *S. anguivi* are reported to be lower. However, the former species is potentially more productive in leaf yield, whereas the latter is said to produce higher quantities of seeds. Investigations comparing 2 cropping systems respectively linked to drip and surface irrigation systems are summarised in table 7 below. The drip system yielded up to 15.3 t/ha higher than the 6 t/ha obtained from the traditional system. The main factors explaining this difference could be related to more effective plant nutrition (fertigation, higher K/N ratio), better plant protection and a slightly longer lifecycle.

**Table 7: Comparative study of traditional and drip irrigation systems**

(Source: Seck, 2006)

| System and areas ($m^2$) | Yields | | Fertiliser application | | | Irrigation | | Pest control cost (US $) | Life-cycle (days) |
|---|---|---|---|---|---|---|---|---|---|
| | kg/ 1250 $m^2$ | t/ha | Organic (t/ha) | N-P-K[12] (kg) | Total NPK (kg) | mm/ day | $m^3$/ cycle | | |
| Drip irrigation (1250 $m^2$) | 1915 | 15,32 | 0 | 190-94-180 | 464,8 | 5,1 | 735 | 76.7[13] | 117 |
| Surface irrigation (1000 $m^2$) | 610 | 6,10 | 3 | 110-110-220 | 440 | 9,09 | 1 000 | 64.8 | 110 |

Figure 20 shows views of fresh eggplants harvested for immediate sales.

**Figure 20: Aspect of fresh African eggplants just after harvest (Bajana, W. Region)**

(Source: Seck, 2009, unpublished)

[12] NPK: total N+P+K in kg/ha: nutrient balance: Drip: 1-0.5-1; surface irrigation: 1-1-2

[13] US $1 = CFA F486 (West Africa, October 2009)

## PRODUCTION COSTS, MARKETING AND USE OF AFRICAN EGGPLANTS

Production costs are variable depending on actual growing conditions, cultural systems and the period as linked to market. An example drawn from the comparative study on drip irrigation (intensive) and traditional system shown in table 7 is summarised in table 8 below.

Total expenses include labour (22% and 59% for the intensive and traditional systems respectively), depreciation (35% and 8%), and inputs (43% and 33%).

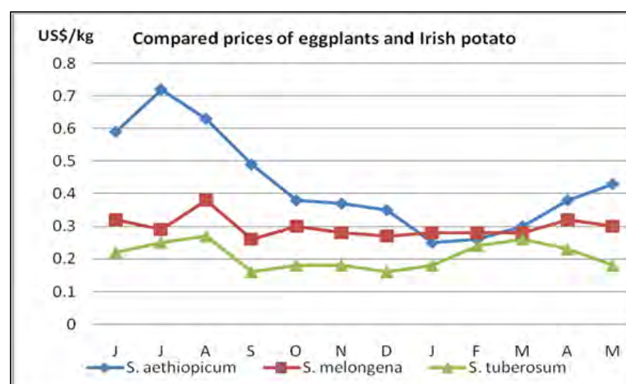
Production costs are different partly due to higher yield in the intensive system (drip): US $0.258 and US $.477. Given the planting date (10 March, 2005), marketing has been carried out in June-July of the same year when selling prices are high.

**Table 8: Production costs of traditional and drip irrigation systems**

(Source: Seck, 2006)

| Items | DI[14] | TS[15] |
|---|---|---|
| Total expenses (US $) | 494.9 | 291 |
| Total turnover (US $) | 2012.6 | 692.4 |
| Production cost (US $/kg) | 0.258 | 0.477 |
| Net margin (US $) | 1252.9 | 377.1 |
| Cash flow (US $) | 1517.7 | 401.6 |

Selling prices are generally variable depending on the period. The figure below shows compared consumer prices of *jaxatu* (*S. aethiopicum*, Kumba), European eggplant (*S. melongena*) and Irish potato (*S. tuberosum*) in one of the biggest vegetable markets in Dakar (unpublished data). It shows that prices for *jaxatu* are generally higher varying from US $ 0.72[16]/kg (July) to $ 0.25/kg (Jan) as compared to European eggplant (US $0.38 and 0.25/kg) and to Irish potato (US $0.27 and 0.16/kg).




[14] DI: Drip irrigation

[15] TS: Traditional system

[16] US $0.72 = CFA F350 (West Africa, October 2009)

**Uses**

The leaves of African eggplants appreciated for their slightly bitter taste are eaten as a separate meal or in sauces. The young leaves and fruits are cooked and consumed as a vegetable. In Uganda, the leaves of the Shum group called *nakati* considered the most abundant leafy vegetables found in markets, are either steamed or fried in oil with onions or consumed with sauces. As to *S. anguivi*, the pea-size bitter fruited cultivars collected from the wild or grown are consumed fresh or dried.

In west Africa, both leaves and fruits are eaten. Members of the Kumba group are reported to be grown for their leaves in Ghana and Burkina Faso (e.g.: Kombi-oree variety) (Schippers, 2002). Big fruits of the Gilo group cultivars are boiled in Ghana and Cote d'Ivoire to thicken sauces. As well, the Kumba group medium to big fruits appreciated in Senegal and Mali are used as condiments just like any other vegetable in rice based dishes. Small fruited cultivars of *S. macrocarpon* called "aubergine du Benin" in French (aubergine of Benin) are consumed as leafy vegetables, whereas in other west African countries big-fruited types are grown for their fruits.

*Other uses*: African eggplants are also used as ornamentals (varieties of Kumba and Aculeatum groups and *S. macrocarpon*) and as medicinal plants (chewed leaves used to cure throat troubles, heart diseases, as a laxative; roots to treat worms, etc.).

African eggplant fruits are less perishable and sensitive to handling than tomato which is softer and more climacteric. However, fresh garden egg berries need to be handled with care to maintain good quality. Fruits are generally packed in onion bags for transport to the marketplace. As it relates to leaves, they should preferably be harvested after copious watering of the crop to maximise and maintain freshness. Packaging is ensured in bundles further to water spraying in case of long distance transport from production areas to marketplace.

Preservation of fruits can be carried out in baskets under ambient conditions for a few days; mid to long-term conservation needs minimum equipment (cold stores) and should be justified by quantities to be handled and expected returns (e.g.: export).

## CONCLUSION AND RECOMMENDATIONS

African eggplants which include 3 main species (*S. aethiopicum* L., *S. macrocarpon* L. and *S. anguivi* Lam.) are key vegetables in Africa and part of the tropical zone. Their importance is related to their place in traditional cropping systems and their role in the communities' food security and nutrition status. In addition, they are now being exported as exotic produce in developed countries. However, they are still neglected in national research and development policies in Africa and as a result, are prone to genetic erosion and disappearance. Through this paper, part of current research findings on the species involved and production practices have been reviewed. Further investigations are needed in various areas, with a few examples reviewed below:

- *Taxonomic issues*: additional work is needed to build on current findings from Lester's and other scientists' work on nomenclature, binomial name of species, different taxa of *S. aethiopicum* and their respective cultivars, etc.
- *Floral biology*: additional work on flower behaviour of all species involved appears to be necessary. Examples of aspects to be explored relate to 50% flowering date and self-pollination rates as linked to varieties and production periods, isolation methods in seed production, etc.

- *Seed germination issues*: Seed embryo dormancy common in the Kumba group, needs further research on the effect of low and high temperatures and on genetic solutions.
- *Inheritance*: very little research has been conducted on this area despite the information available. For example, the genetic determinism of antixenosis resistance to mites linked to leaf hairiness (completely or partially inherited character) needs more focus; as well as *S. macrocarpon*'s resistance observed despite its glabrous leaves calls for further genetic studies for clarification; in addition, follow-up research on preliminary results obtained on other aspects (anthocyanins content, fruit colour and shape, etc.), is needed; other examples relate to the type of inflorescence (cyme or truss) linked to fruit size and yield, etc.
- *Hybrid varieties*: studies on heterosis on African eggplant need more focus; in particular, combining abilities through diallel crosses should be confirmed on intraspecific crosses. The findings expected should justify and facilitate hybrid breeding and production, for both internal markets and export.
- *Insect and mite resistance*: The available findings on the effect of leaf hairs on mite infestation need to be confirmed as well as the reported resistance of *S. sisymbrifolium* and *S. macrocarpon*; in addition, the flower bud borer is an urgent matter to work on (e.g. looking at genetic variability at intra and interspecific levels).
- *Nematode resistance*: as seen above, genetic variability does not seem to be readily available in closely related species (*S. macrocarpon* and *S. anguivi*). Investigations might be justified in other non-tuberous Solanums reported resistant (e.g.: *S. sisymbrifolium* and *S. torvum*).
- *Resistance to Stemphylium/Alternaria*: the good response to artificial inoculation of the Gilo group accessions [0-3% of infection (Demaeyer, 1985)] might be linked to leaf hairs and needs more research.
- *Organic production*, becoming the buzz word in horticulture, is however not being fully exploited due to lack of readily usable technical packages. As a result, additional work is needed on aspects like organic fertilisers, biological/organic pest control (e.g.: botanicals), optimal plant densities likely to compensate yields, etc.

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[17] CECI (Centre Canadien d'Etudes et de Coopération Internationale);PAEP (Project d'appui à l'Entrepreneuriat des Paysans) ; ACDI (Agence canadienne pour le Développement International)

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# ANNEXES

## Annex 1: Systematic classification and nomenclature of *Solanum aethiopicum* L.

(Source: R.N. Lester, personal communication to Daunay)

| Groups | Section | Series | Species | | Area of origin |
|---|---|---|---|---|---|
| | | | Usual name | Correct name (Lester) | |
| Anguivi | Oliganthes Bitt. | Afroindica Bitt. | *S. distichum* (Shum & Thonn.)<br>*S. rohrii* C.H. Wright<br>*S. scalare* C.H. Wright<br>*S. anomalum* Auct. Non Thonn. | *S. anguivi* Lam. | Africa |
| Aethiopicum | Oliganthes Bitt. | Aethiopica | *S. zuccgnianum* (Dun.)<br>*S. gilo* Raddi<br>*S. integrifolium* Poir (*S. texanum* Dun)<br>*S. anomalum* | *S. aethiopicum* L., subspecies:<br>• Shum<br>• Gilo<br>• Aculeatum<br>• Kumba | West and central Africa;<br>Brazil |

## Annex 2: Aspect of flowers and inflorescences in different groups of *S. aethiopicum* L.

(Source: Seck, 1986)

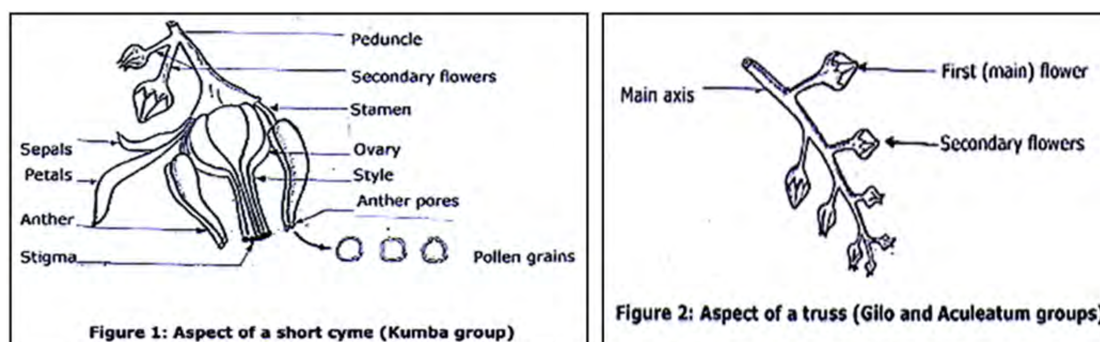



Figure 1: Aspect of a short cyme (Kumba group)

Figure 2: Aspect of a truss (Gilo and Aculeatum groups)

## Annex 3: Results of inter-group and interspecific crosses and cross attempts of eggplants

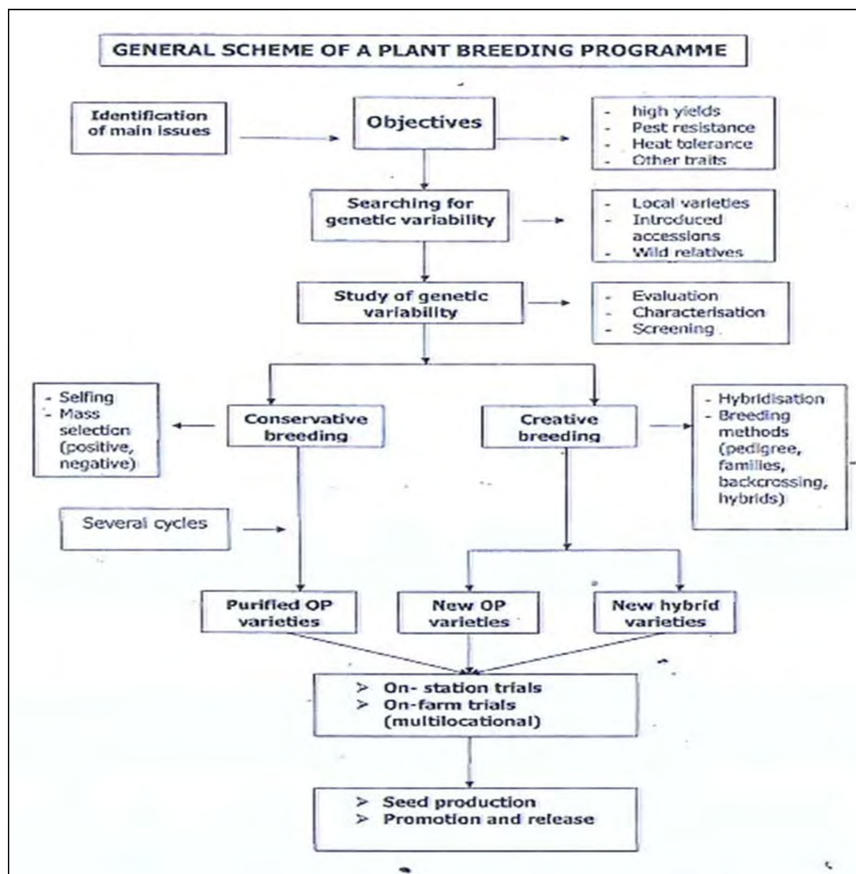
| Combinations/cross attempts | Results of crosses | | Authors |
|---|---|---|---|
| | Success | Failure | |
| *S. aethiopicum* (Aculeatum) x *S. sisymbrifolium* | | x | Rao (1979)**** |
| *S. aethiopicum* (Gilo) x *S. sisymbrifolium* | | x | Rao (1979)**** |
| *S. aethiopicum* (Kumba, Gilo, Aculeatum) x *S. sisymbrifolium* | | x | Seck (1984) |
| *S. aethiopicum* (Kumba, Aculeatum) x *S. torvum* | | x | Seck (1984) |
| *S. aethiopicum* (Kumba, Gilo, Aculeatum) x *S. macrocarpon* | | x | Seck (1984) |

| S. melongana x S. aethiopicum (Aculeatum) | x* | | Daunay et al. (1993)** |
|---|---|---|---|
| *S. macrocarpon* x *S. melongena* | x | | Gowda et al. (1990)** |
| *S. aethiopicum* (Kumba, Gilo) x *S. anguivi* | x | | Lester (1982); Seck (1984) |
| *S. aethiopicum* (Kumba) x *S. anguivi* | x | | Seck (1984) |
| *S. aethiopicum* x *S. macrocarpon* | x*** | | Omidiji (1979)**** |
| *S. melongena* x *S. aethiopicum* (Gilo) | x | | Daunay et al. (1993)***** |

*: somatic hybrids; **: Reported by Sekara et al. (2007); ***: Partially fertile $F_1$'s; ****: Reported by Seck (1986); *****: Fertile somatic hybrids obtained (Sekara et al., 2007)

**Annex 4**

(Source: Seck, 2008)



# Good Agricultural Practices for African Nightshade Production in Sub-Saharan Africa

**Gideon N. Mwai[1], Chris O. Ojiewo[2], Peter W. Masinde[3] and Stephen G. Agong[4]***

*[1]Maseno University, Maseno, Kenya*
*[2]ICRISAT-Malawi, Chitedze Agricultural Research Station, Box 1096, Lilongwe, Malawi*
*[3]JKUAT, Nairobi, Kenya*
*[4]Bondo University College, Bondo, Kenya*
**Corresponding author (sgagong@ymail.com)*

**Abstract**

African nightshades (*Solanum nigrum*-related species) are important indigenous green leafy vegetables traditionally consumed by rural communities in most parts of Africa. The genetic diversity in these vegetables is quite huge and rich for possible improvement work. The vegetable has been gradually introduced to urban areas through rural-urban migration, necessitating market gardening. Notably, the consumption of these vegetables is on the increase, making them promising alternative cash crops locally, and for export. With the realization of their high nutritional value, medicinal and health benefits, the demand for these vegetables has been on a rapid and steady rise in recent years. Currently, the production of African nightshades is undergoing transformation from kitchen gardening to market gardening. This has been brought about by the increased demand of these vegetables in the urban areas through the supermarkets, groceries, retail-markets and hotels outlets. Moreover, farmers grow these vegetables primarily for their own consumption and sell only what is considered excess. Integration of these crops into mainstream horticulture has been very slow, due to low leaf yields that are considered uneconomical compared to other high yielding and high-value horticultural crops. Growers of African nightshade obtain yields of about 3.0 tonnes $ha^{-1}$ which compares dismally to potential yields of about 30 tonnes $ha^{-1}$. To keep up with increases in consumption and demand, there is an acute need for the rapid domestication and commercialization of these vegetables. This paper reviews the genetic diversity of African nightshades and highlights the common agricultural practices for safe and sustainable production. The need for a systematic cultivar development and improvement is also discussed.

## GERMPLASM, TAXONOMY AND DIVERSITY OF AFRICAN NIGHTSHADES

The section *Solanum*, centring on the species commonly known as black, garden or common nightshades (*Solanum nigrum*-related species) is one of the most ubiquitous, largest and most variable species groups of the genus. Although the *S. nigrum*-related species are distributed throughout the world, they occur in their greatest concentrations in tropical and warm temperate regions with centres of diversity occurring in South America, Australia and Africa, with relatively few and less diverse species being found in Europe and Asia (D'Arcy, 1991). The taxa of African origin are referred to as African nightshades. For a long time, members of the section *Solanum* have been regarded as poisonous species or dangerous weeds, especially by developed countries. The garden nightshades are probably confused with the deadly nightshade (*Atropa belladonna*), which has highly toxic leaves and berries. Tolerance of many habitats, ability to flower while young and prolific seed production are key factors in their evolutionary success (Schippers, 2002). The centers of diversity for diploid section *Solanum* species are South and North America, while the centers of origin of most polyploid species (tetraploids and hexaploids) are in Europe or Africa. *Solanum scabrum* (hexaploid) and *S. villosum* (tetraploid), which are most widely cultivated vegetable nightshades, have

their widest diversity in Africa. Nightshades are among the most popular and common leafy vegetables, particularly in the warm humid regions in Africa, and are only second to amaranths among important leafy indigenous vegetables. In some areas of west Africa, they are reportedly the most important leafy vegetable crop (Berinyuy et al., 2002).

The taxonomy and nomenclature of nightshades is complex due to various reasons including extensive synonymy, frequent occurrence of spontaneous inter-specific hybrids, existence of a polyploid series, phenotypic plasticity, existence of many local names and discordant genetic variation (Edmonds and Chweya, 1997). The taxonomic complexity associated with African nightshade species has led to considerable confusion regarding the identity of popular vegetable species. For example, whereas most literature refer to Africa's edible nightshades as '*Solanum nigrum*', such reference in reality could apply to any one of at least five edible species including *Solanum scabrum*, *S. americanum*, *S. villosum*, *S. florulentum* and *S. tarderemotum*; and there is no evidence that the real *S. nigrum* is among the popular vegetable species. Furthermore, *S. tarderemotum* is poorly understood despite being a relatively important vegetable species in eastern Africa, often being referred to by synonyms such as *Solanum eldorettii*, *S. florulentum* and *S. nigrum* (Dehmer and Hammer, 2004; Mwai and Schippers, 2004; Olet et al., 2005).

Currently, the largest known and well-maintained collection of edible African nightshade species within the continent is at the regional center for Africa of AVRDC-The World Vegetable Center in Arusha, Tanzania. Natural inter-specific hybridization is widely reported to occur in *Solanum* section *Solanum*, with the resultant hybrids often undergoing genetic breakdown in $F_1$ or $F_2$ generations, which explains occurrence of plants that flowered profusely but failed to fruit observed in recent studies by Mwai (2007) on the AVRDC collection. Furthermore some of the accessions were mixed, sometimes containing up to three different species. Identification of specimens from such populations is difficult (Edmonds and Chweya, 1997).

**Figure 21: Morphological features of *S. americanum*. Erect/spreading habit (i & ii); entire-undulate leaves with no pubescence. Flowers white, yellow anthers (iii). Erect pedicels with dark purple shiny berries (iv) that drop from pedicels when fully ripe (v).**

**Figure 22: Morphological features of purple-stemmed *S. scabrum* variant. Erect habit; large leaves (i & ii); with varying intensities of purple coloration; dark purple berries (iii). Flowers (iv) usually deep purple with brown anthers.**

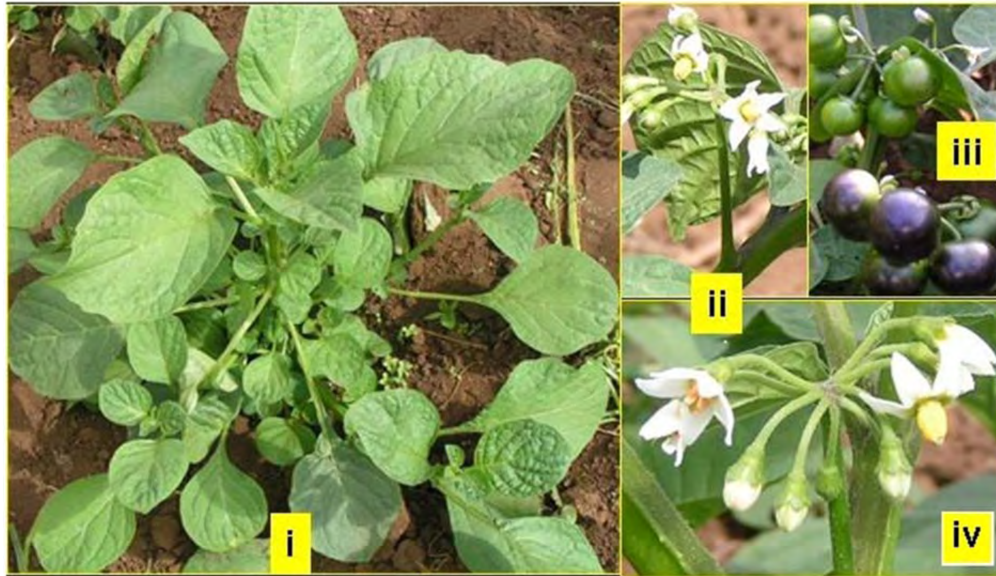



**Figure 23: Morphological features of green-leaved *S. scabrum* variant. Erect habit; leaves large (i); few flowers per inflorescence (ii), berries ripen to dark purple (iii); leaves and stems green; flowers white with yellow anthers (iv).**

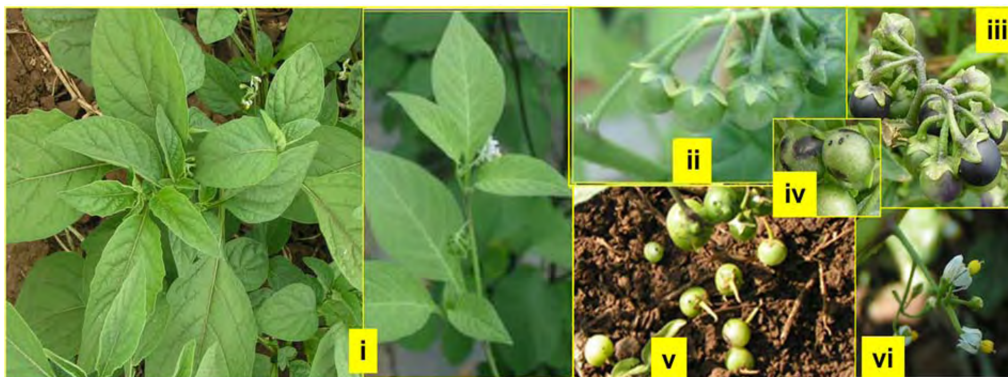



**Figure 24: Morphological features of *S. tarderemotum*. Variable leaf morphology (i); berries light green (ii), purple (iii), or green with purple patches (iv) when ripe; always drop with pedicels (v). Inflorescence may be simple (ii) or branched (vi).**

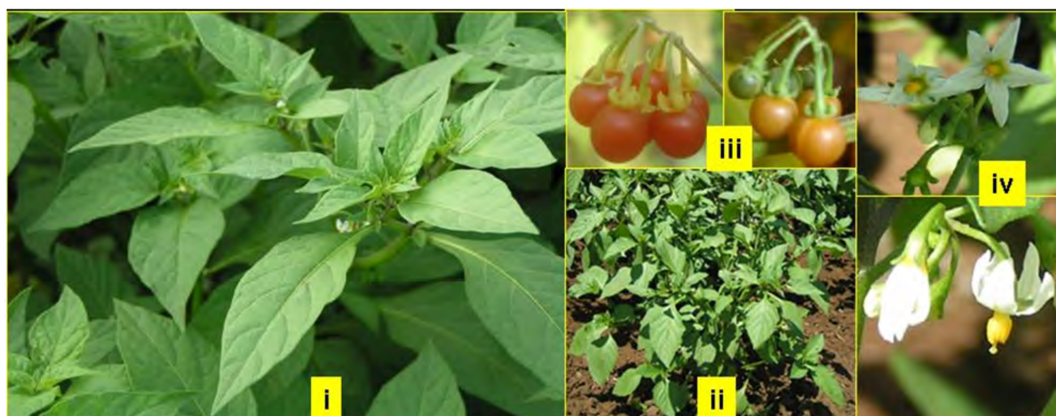



**Figure 25: Morphological features of *S. villosum* with entire/undulate leaf margins (i), erect growth habit (ii) and deep-orange to red ripe berries (iii); some flowers have slightly exserted styles (iv bottom).**

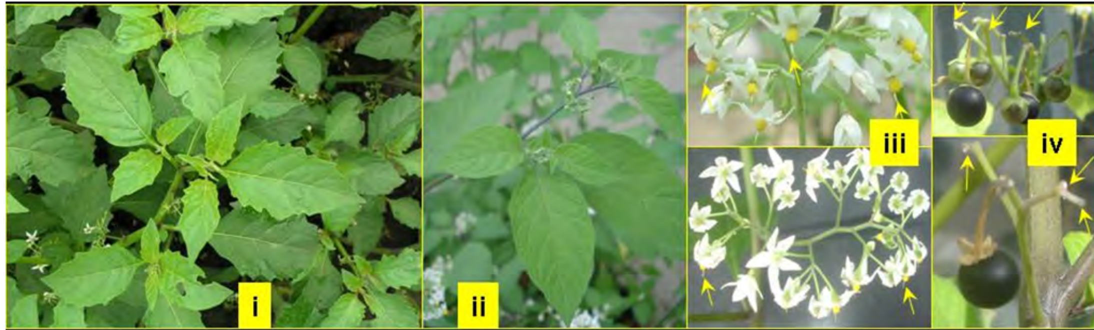



**Figure 26: Morphological features of *S. florulentum*. Leaf morphology (i & ii). Inflorescences extensively branched (iii). Berries turn dull purple (iv) and drop with pedicels (see arrows in iv) when fully ripe.**

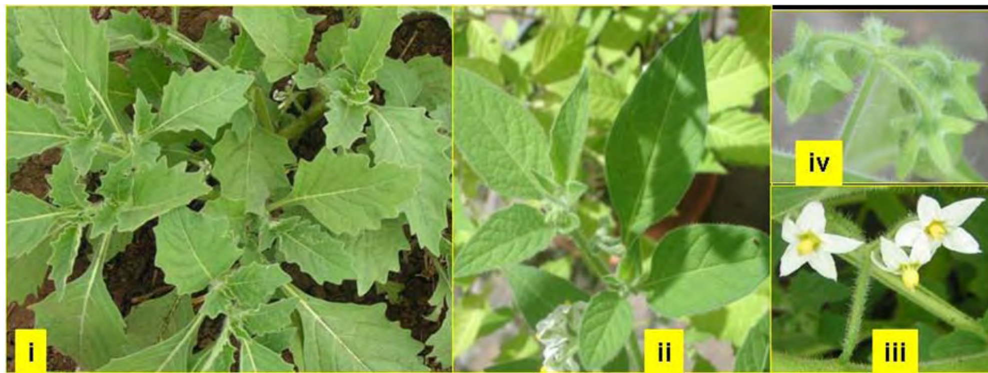



**Figure 27: Morphological features of *S. grossidentatum*; with dense long white glandular hairs on leaves (i & ii), stems, peduncles, pedicels and calyces (iii and iv); fully ripe berries light to yellowish green (iv).**

Schippers (2002) and Edmonds and Chweya (1997) reported that four nightshade species are cultivated in Africa for their leaves, including *S. scabrum*, *S. villosum*, *S. americanum* and *S. eldorettii* whereas Mwai (2007) identified six species including *S. americanum* (Figure 21), *S. scabrum* (Figures 22 and 23), *S. tarderemotum* (Figure 24), *S. villosum* (Figure 25), *S. florulentum* (Figure 26) and *S. grossidentatum* (Figure 27) all of which are used as leafy vegetables in Kenya and Tanzania although only the first four are cultivated. Similarly, Olet (2004), working on Ugandan species has observed six species including *S. americanum*, *S. villosum*, *S. hirsutum*, *S. florulentum*, *S. tarderemotum* and *S. scabrum*. It is probable that *S. grossidentatum* and *S. hirsutum* collected in Kenya and Uganda by Mwai (2007) and Olet (2004), respectively are closely related. *S. grossidentatum* reported by Mwai (2007) is superficially very similar to *S. sarrachoides*, and had indeed been mis-identified as such. However, cytological (Mwai, 2007) and crossability (Manoko, 2007) studies revealed the material to be tetraploid, whereas *S. sarrachoides* is diploid, hence the correct identification as *S. grossidentatum*. *S. retroflexum* is reported to be cultivated in South Africa for its fruits and leaves (Jacoby et al., 2003). A recent diversity study on the AVRDC collection (Mwai, 2007) reported high degree of genetic diversity among African vegetable nightshades. *Solanum scabrum* exhibited the highest intra-specific diversity, with six morphologically distinct clusters/variants, *S. villosum* was second and had two; *S. grossidentatum* and *S. americanum* had one cluster each; while *S. florulentum* and *S. tarderemotum* formed a single cluster (Figure 28). Morphological diversity in *S. scabrum* was broadly recognizable between plants with purple corolla, brown anthers and purple leaves and stems on one hand; and those with white corolla, yellow anthers and green leaves and stems on the other. Berinyuy et al. (2002) and Fontem and Schippers (2004), studying diversity of *S. scabrum* in Cameroon where it is widely grown as a leafy vegetable, reported 12 recognizable variants while Olet (2004) recognized two *S. scabrum* subspecies in Uganda. Observations by other authors also

suggested the existence of two subspecies being recognized in Africa as *S. villosum* (Schippers, 2002; Manoko and van der Weerden, 2004b; Olet et al., 2005). Diversity of the other species as presented by Mwai (2007) was quite low unlike the previous investigations which revealed high genetic diversity.

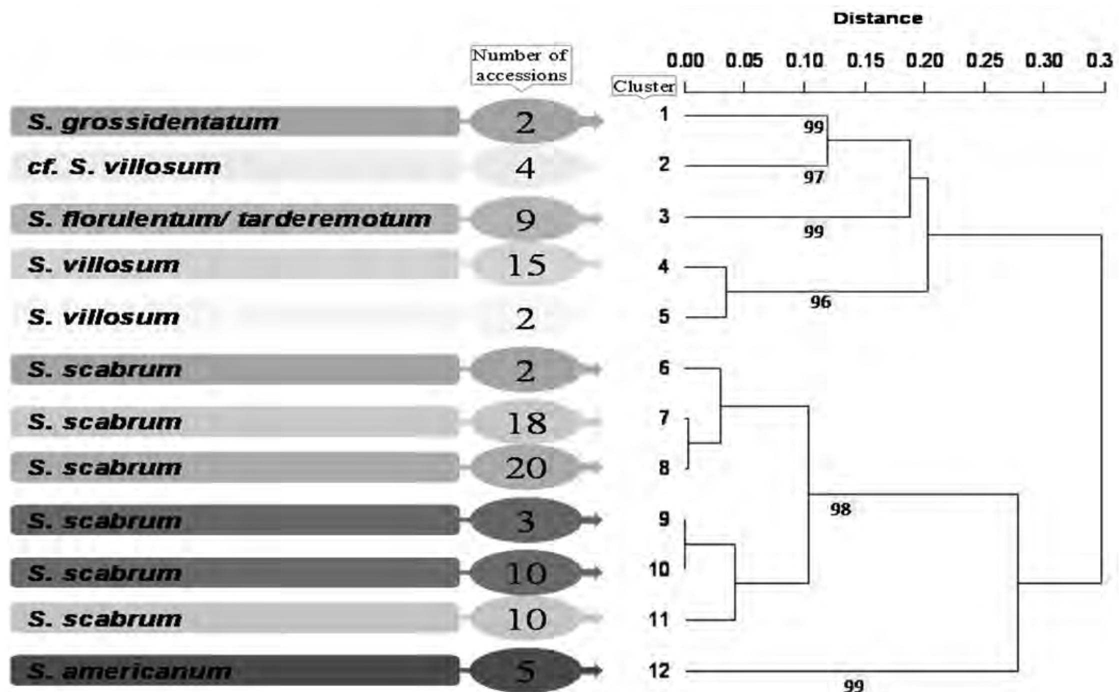



**Figure 28: Dendrogram showing the morphological diversity in the AVRDC African nightshade collection, comprising 100 accessions characterized using 47 morphological descriptors. The dendrogram was pruned using Kelley-Gardner-Sutcliff penalty function to show the 12 morphological statistically supported groups. Figures show bootstrap probability support values for clusters defining each species.**

## BREEDING AND GENETIC IMPROVEMENT OF THE AFRICAN NIGHTSHADES

Yields of the African nightshade collections obtained at AVRDC reportedly ranged from 4.81 tonnes $ha^{-1}$ to 71.81 tonnes $ha^{-1}$, and per season for leaf (Figure 29). Consistently, *S. scabrum* accessions recorded the highest leaf, berry and seed yields. Earlier studies reported comparable leaf yields for vegetable nightshades ranging between 32 tonnes $ha^{-1}$ and 48.8 tonnes $ha^{-1}$ (Edmonds and Chweya, 1997; Schippers, 2002). Mwai (2007) recognized three growth habits along which leaf yield of vegetable nightshades could be patterned. *S. scabrum* accessions had large leaves, and only primary and secondary branches, thereby attaining high leaf area index (LAI) by maximizing the size of individual leaves and thereby attaining very high leaf yields. *S. grossidentatum*, *S. villosum*, *S. florulentum* and *S. americanum* had much smaller leaves compared to *S. scabrum* but branched profusely, attaining a bushy growth habit, hence maximizing their LAI by initiating a large number of leaves borne on numerous lateral shoots. The third growth habit comprised some *S. villosum* accessions (cluster 5 in Figure 28) and *S. tarderemotum*, which formed compact plants with primary and secondary branches only. With neither the advantage of large leaves nor many branches/leaves, these were unable to attain photosynthetic efficiencies as high as those in the first and second groups at the density used in this study and hence produced the lowest leaf yields. The high yields of *S. scabrum* could also be attributed to the higher ploidy level, which would expectedly confer larger plant dimensions to this hexaploid species compared to diploids and tetraploids (de Jesus, 2003).

Due to the higher yield potential, *S. scabrum* has been cited as popular among commercial producers for urban markets (Chweya and Eyzaguirre, 1999; Mwai, 2007) and as the most important vegetable nightshade species due to its considerable diversity in vegetative features and fruits (Lester and Daunay, 2003; Fontem and Schippers, 2004; Manoko and van der Weerden, 2004a).

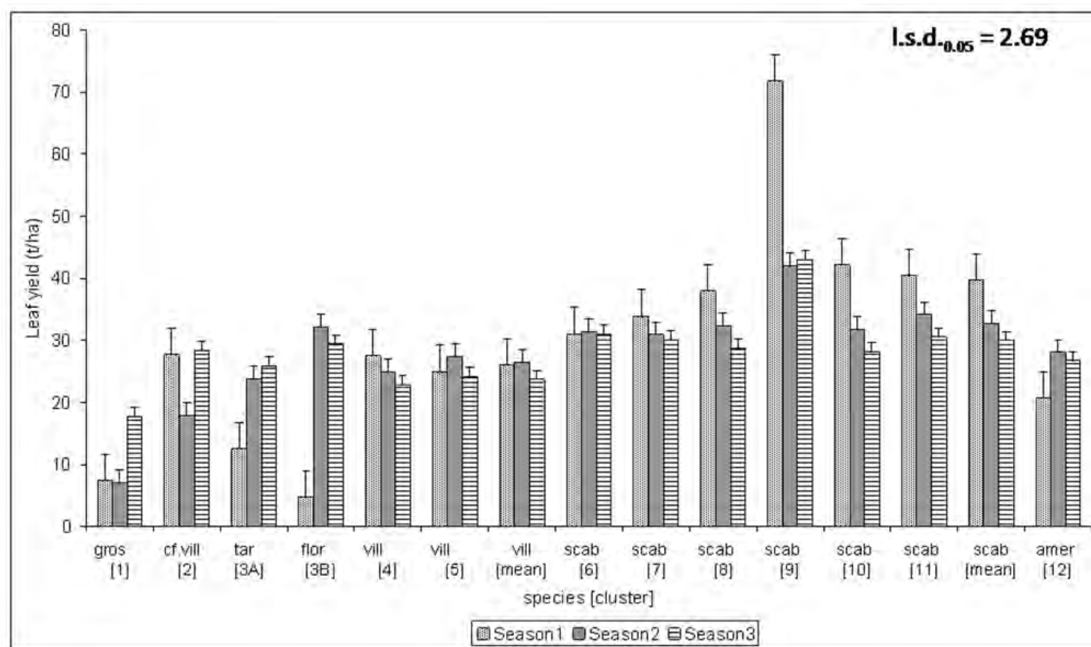



**Figure 29: Leaf yield (t/ha) of morphological clusters of African nightshades evaluated for three seasons: flor= *S. florulentum*; vill= *S. villosum*; cf.vill= cf. *S. villosum*; gross= *S. grossidentatum*; scab= *S. scabrum*; amer= *S. americanum***

Breeding and genetic improvement would also be geared toward eliminating the toxicity widely associated with nightshades considered mainly to be attributed to the presence of steroidal glycoalkaloids (SGAs). Although SGAs are harmless and are even reported to enhance flavor at low levels, they impart bitterness and varying degrees of toxicity and death in animals and humans at high levels (Lawson et al., 1992; Turakainen et al., 2004). TGA concentrations above 140 mg/kg of fresh weight are associated with bitter taste and unpleasant flavor. The recommended upper TGA limit in plant foods is 200 mg/kg fresh weight (1 g/kg dry weight). Yencho et al. (1998) and Laurilla (2004) pointed out that since glycoalkaloids are highly heritable polygenic traits, breeding solanaceous crops for resistance to pests/diseases and agro-ecological conditions may result in unintended increase in TGA content (Figure 30).

Mwai (2007) reported total glycoalkaloid content in vegetable nightshade leaves ranging between 78.97 mg/kg fresh weight to 168.85 mg/kg fresh weight, with mean TGA contents in the most widely cultivated species being 116.80 mg/kg, 100.82 mg/kg and 112.97 mg/kg in *S. scabrum*, *S. villosum* and *S. tarderemotum* respectively (Figure 30). These values were well below the recommended upper limit of 200 mg/kg fresh weight TGA in plant foods (Laurilla, 2004; Turakainen et al., 2004), hence the conclusion that leaves of popular African vegetable nightshades do not contain toxic levels of SGAs (Mwai, 2007). It should, however, be noted that toxicosis by SGAs would be the result of interactions between several factors including absolute amount of TGA ingested, body weight of the consumer, rate at which SGAs are metabolized, and the relative toxicity of individual SGAs present (Friedman et al., 2003; Ramsay et al., 2004).

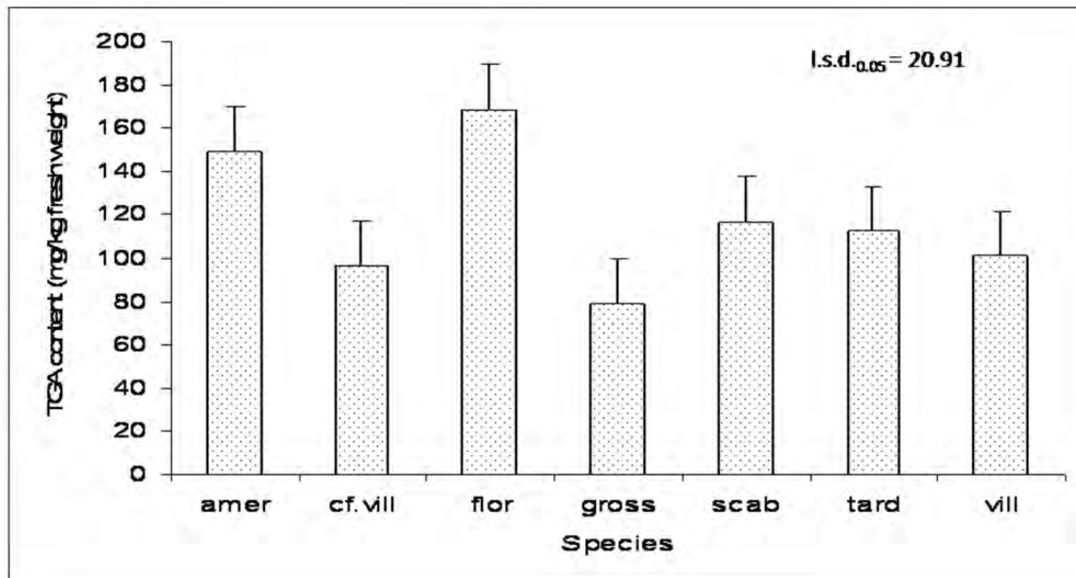



**Figure 30: Total steroidal glycoalkaloid content in vegetable African nightshades: amer= *S. americanum*; flor= *S. florulentum*; vill= *S. villosum*; cf.vill= cf. *S. villosum*; gross= *S. grossidentatum*; scab= *S. scabrum***

(Source: Mwai, 2007)

Notably, deflowering increased leaf yields by 40% (Mwafusi, 1992). Elimination of the suppressing effect of fruits could account for such increases. As deflowering is costly, cumbersome and labour intensive, introduction of new varieties with improved and stable yields has been proposed as an economically viable and technically feasible way forward (Ojiewo et al., 2005). Selection, induction or introduction of novel varieties with suppressed or delayed on-set of reproductive growth is a promising strategy to improve and stabilize yields of these vegetables. Some of the tools that can be used to achieve this include self-incompatibility (SI), induced heteroploidy and male-sterility. The success of each approach depends on technical feasibility, economic viability and social acceptability of the final product, the novel cultivar. Self-incompatibility is the inability of a fertile hermaphrodite seed plant to produce zygotes after self-pollination (Lundkvist, 1964). Although SI is widespread in nature among angiosperms, it does not occur among the African nightshades and mutagenic induction in other species has not been successful so far. The use of SI therefore, faces technical challenges. Heteroploids are organisms or cells having a chromosome number that is not an even multiple of the haploid chromosome number for that species. During the meiosis of heteroploids, heterovalents are formed (Cassani and Caton, 1985). In anaphase I, the chromosomes are distributed between the daughter cells, both of which have incomplete sets (aneuploidy), leading to lethality. Heteroploidy therefore, generally causes sterility (or strongly reduced fertility) of both pollen and ovules. Thus, it is a promising tool. Male-sterility is the failure of plants to produce functional anthers, pollen, or male gametes. Male-sterility can be a result of gene mutation, inter- and intraspecific hybridization, radiation, chemicals, genetic engineering or environmental factors. Induction of male-sterility through conventional mutation methods may involve the use of physical or chemical agents. As ample potent mutagens are available, induction and selection of male-sterile mutants can be achieved easily. *Solanum* section *Solanum* constitutes a polyploid series, with diploid (e.g. *S. americanum*, *S. physalifolium*, *S. chenopodioides*, and *S. sarrachoides*) tetraploid, (e.g. *S. retroflexum*, *S. villosum*, *S. excisirhombeum*, *S. fragile* and *S. interandinum*) and hexaploid (e.g. *S. nigrum*, *S. furcatum*, *S. scabrum*, *S. arequipense* and *S. macrotonum*) species. Octoploid plants (2n=8x=96) have also been reported (Edmonds, 1979).

Progress on the use of heteroploidy as a strategy for modifying dry matter distribution to favour leaf productivity of *S. villosum* after anthesis was hampered by reciprocal cross-incompatibility between the octoploid mutant and its wild-type parent and with related pollen sources (Ojiewo et al., 2006a, 2007a). Artificial hybrididization in most *S. nigrum*-related taxa has been unsuccessful with the resultant 'hybrid' berries being empty or containing inviable seeds. Any resultant hybrid seed often gave rise to sterile $F_1$ plants or to $F_2$ generation plants exhibiting genetic breakdown (Edmonds, 1979). Successful crosses are more difficult between taxa of differing ploidy levels than they are between taxa of the same chromosome number, with interploidy crosses leading to the development of morphologic intermediate but sterile progeny, at best. Possible causes of the genetic breakdown encountered range from genome disharmony to genic or chromosomal sterility, with the crosses failing pre- or post-zygotically (Edmonds, 1979). Studies on pollen-pistil interactions and ways of overcoming this cross-incompatibility will be necessary to overcome this hybridization barrier and ensure the success of heteroploidy breeding schemes.

The occurrence of polyploidy in *Solanum* section *Solanum* is probably the most significant barrier to natural and artificial hybridization among these species. Introgression of useful traits across different ploidies is therefore a major challenge.

Pollen and anther mutant male-sterile lines successfully induced (Ojiewo et al., 2006b): (i) an acetocarmine-stained nonviable pollen type which stained black with potassium iodide solution (T-1); (ii) a defective aborted pollen type not stainable with acetocarmine (T-2); (iii) a pollen-less type with defective anthers (T-3); and (iv) an extremely low pollen-producing type (T-4) (Figure 31). The T-1 pollen that stained positively with iodine probably did not breakdown starch at anthesis (Goetz et al., 2001). The T-3 and T-4 mutants probably had defects in functional microspore production leading to degeneration of cells within the anther locules (Sanders et al., 1999). In addition, an abnormal floral organ mutant (T-5) whose flowers had leaf-like sepals in all floral whorls from winter through mid-spring, were mostly stamenless in late-spring, indeterminate in summer and partially restored with seeded berries in autumn, has also been induced (Ojiewo et al., 2006b; Figure 32). Floral organ restoration was found to be influenced by day/night temperature but largely independent of photoperiod conditions (Ojiewo et al., 2007b). Day/night temperatures of 25/25 and 30/20°C favoured restoration of the floral organ but most flowers were stamenless and infertile. High night temperature led to formation of indeterminate flowers both in the growth chamber (30°C) and in the greenhouse (>25°C). On the other hand, low growth chamber (10°C) and greenhouse (<15°C) night temperatures favoured the formation of sepaloid flowers. The optimum temperatures for floral structure and fertility restoration were between 20-25°C (day) and 15-20°C (night). Thus, propagation of T-5 mutant can be achieved by growing in regions or seasons with such temperature ranges. Under temperatures unfavourable for fruit-set, leaf productivity is expected to be high.

The T-5 produced 9.6% (143.7 g/plant) and 22.7% (147.4 g/plant) more biomass than the W-T in 2005 (131.2 g/plant) and 2006 (120.2 g/plant), respectively. Furthermore, the T-5 allocated 27.3 and 31.31% while the W-T allocated 19.2 and 19.5% of the total plant matter to leaves in 2005 and 2006, respectively. Conversely, while the T-5 allocated only 2.81 and 0.93%, the W-T allocated 40 and 33.81% of the total plant biomass to fruits in 2005 and 2006, respectively (Ojiewo et al., 2009). These results were attributed to elimination of the suppressing effects of fruits and seeds on vegetative growth. Male-sterility and the accompanying change in reproductive:vegetative balance is clearly a useful tool for circumventing source-sink imbalances that reduce leaf yields after anthesis in African nightshades. Adaptability studies under African conditions are necessary.

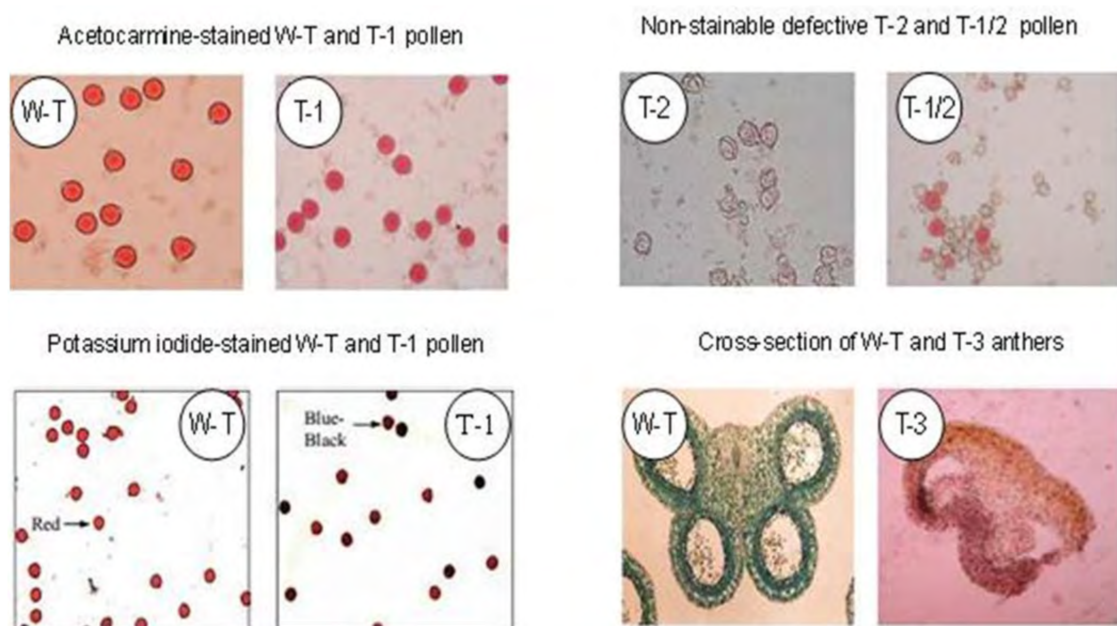



**Figure 31: Photomicrographs showing the pollen and anther-staining patterns and defects: Acetocarmine-staining of wild-type fertile pollen (W-T) and non-viable pollen (T-1); potassium iodide-stained (red) wild-type pollen (W-T) and black stained T-1 male-sterile mutant pollen; defective pollen not stainable with acetocarmine (T-2) and mixed stainable and non-stainable pollen (T1/2); transverse sections of anthers showing four distinct anther lobes with pollen-filled wild-type (W-T) locules and abnormal anther walls and empty locules of the pollenless mutant (T-3)**

**Figure 32: Seasonal changes in flower structures in T-5 mutant. Left-to-right: normal, W-T inflorescence; T-5 sepalloid buds in mid-spring; stamenless flowers in late-spring; indeterminate flowers in summer; partially restored flowers in autumn; and non-restored flowers in winter**

Selection of nightshade for late flowering among the available natural diversity also holds a high potential as long as selected likes suit the tastes and preferences of the consumers. *S. scabrum* accessions are of particular potential in this regard. In Tanzania, participatory variety selection and evaluation has helped identify 8 lines which are currently undergoing multilocational testing for possible release. Line BG 16 with large succulent leaves, late flowering habit and fast sprouting of new leaves after harvesting, holds the highest potential. These traits give it a comparative advantage during vegetative growth due to minimal competition with the reproductive function, leading to high leaf yields. The prolonged vigorous vegetative growth is also advantageous for accumulation of photoassimilates for later reproductive growth, thus leading to high seed yields (Ojiewo et al., Unpublished).

## AGRONOMIC REQUIREMENTS FOR SUSTAINABLE PRODUCTION OF AFRICAN NIGHTSHADES

Although they perform well in a wide range of climatic conditions, nightshades grow best under cool moist conditions in medium to high altitudes. Optimum growth temperatures range between 15°C and 35°C. Low light intensities favour germination, but at sub-optimal temperatures, intermittent light enhances germination. Shade causes a decline in the total plant weight and leaf yield, although leaf production is unaffected by light shade. They

tolerate shade, but grow better when exposed to full sunlight, as long as adequate water is available. However, leaves harvested from shade-grown plants are less bitter than those harvested from plants grown in the full sun. Nightshades are generally intolerant of water deficit, and thus thrive during the rainy seasons in the tropics; with annual precipitation of 500-1200 mm being adequate for growth. They perform best during high rainfall seasons, but such conditions also increase the prevalence of foliar diseases. They grow in various soil types, but are best adapted to soils of high fertility; especially those rich in nitrogen, phosphorus and organic matter. Sandy loams to friable clay soils with a pH range of 6.0-6.5 are particularly suitable (Fawusi, 1983; Edmonds and Chweya, 1997).

Propagation of African nightshades is mainly by seed. However, seeds may be difficult to obtain for some species such as *S. tarderemotum* and *S. americanum* whose berries drop to the ground as they mature (Mwai and Schippers, 2004). Seeds may be sowed either directly in the field or raised in a seedbed and later transplanted. One gram contains about 1000 seeds for *S. scabrum*, and 2000-3000 seeds for other species (Mwai, 2007). Seeds may be sowed either directly in the field or raised in a seedbed and later transplanted. Production for subsistence consumption is mainly by direct sowing or broadcasting at the beginning of the rainy season. Direct sowing during the rainy season results in stronger and larger plants, which yield more compared to transplanted ones. 3-10 seeds are used per location, and the strongest seedlings retained, while the rest are thinned and transplanted or used as vegetable. Few seeds per location should be maintained to avoid spindly seedlings (Schippers, 2002; Edmonds and Chweya, 1997).

The common practice in commercial production is to raise seedlings in fine-tilled seedbeds with generous amounts of manure, wood ash, or both. The land should be prepared by digging to a depth of 30 cm and well-decomposed manure worked in. It is highly advisable to sterilize the nursery soil before sowing because nightshade seedlings are very susceptible to damping-off disease (Mwai, 2007). Burning a layer of dry straw on the bed before sowing sterilizes the soil, eliminates soil-borne pathogens, pests and weeds, and adds nutrients such as potash. Alternatively nursery soil should be solarized for one to two weeks prior to sowing. Seeds should be sown in rows that are 10-20 cm apart, and should not be buried more than 2 cm deep. Placing the seeds too deep will result in poor germination. Alternatively, seed may be broadcast and covered with a thin layer of soil. Seeds may be mixed with sand, fine dry manure, soil or ash to spread them more evenly during sowing. Dry grass mulch should be applied, and removed when seedlings are about 3 cm tall. Seedling emergence takes 5-9 days under favorable conditions, or longer when soil moisture is inadequate. Seedlings are ready to transplant 3 to 4 weeks after emergence, and should be hardened by reducing the frequency of irrigation in the week prior to transplanting. Transplanting operations should be in the afternoon or under cloudy conditions to minimize transplanting shock (Schippers, 2002; AVRDC, 2004; Mwai, 2007).

Seedlings of 3 to 4 weeks after emergence, at least 8 cm tall and with 5-6 leaves are ready for transplanting to fine-tilled and well manured plots. Leaving the seedlings too long in the nursery makes them weaker and more prone to transplant shock. Seedlings should be hardened by reducing the frequency of irrigation in the week prior to transplanting, but thoroughly watered just before transplanting to reduce root damage during uprooting. Transplanting operations should be in the afternoon or under cloudy conditions to minimize transplanting shock. Only strong and disease-free seedlings should be transplanted. Adequate water is required immediately after transplanting since the seedlings are sensitive to drought and good soil-root contact ensured by covering the roots properly with soil and applying slight pressure. Gap filling should be done as soon as possible to ensure a uniform crop (Schippers, 2002). Shoot cuttings may also been used, whereby 20-30 cm cuttings from strong stems are inserted into well-watered and fertilized soil. Although cuttings result in a fast crop where harvesting starts after 3-4 weeks, the plants branch, spread and yield less; and contain more glycoalkaloids compared to seed-propagated plants (Edmonds and Chweya, 1997).

Spacing may differ depending on the species or variety, the intended crop duration, growing season, and whether the crop is for leaf or seed production. Wide spacing is generally used for seed production, and long/rainy season crops. For example, wider spacing during the long rainy season is recommended to allow sufficient air circulation, which reduces conditions favorable to the development of diseases (Schippers, 2002). Recent studies found that leaf yield responded significantly to increasing planting density, with the highest plant density evaluated (10 plants/$m^2$) producing the highest leaf yield, but berry yield and seed yield did not differ significantly between various plant densities (Table 9). Therefore, for leaf yield, the net benefit of increased plant density in achieving a comprehensive canopy and consequent high photosynthetic efficiency out-weighed the growth of individual plants, but was not beneficial for reproductive growth (berry and seed yield). Therefore a high plant density of 10 plants /$m^2$ was recommended for leafy crops; while wider spacing of 60x50 cm or 80x50 for berry/seed crops would not only be economical in terms of reduced inputs, but would encourage stronger branching and better quality (Mwai et al., 2009b).

**Table 9: Leaf, berry and seed yield in selected African nightshade accessions in response to spacing**

(Source: Mwai, 2007)

| Spacing (cm) | Leaf yield (g/plant) | Leaf yield (t/ha) | Berry yield (g/plant) | Berry yield (t/ha) | Seed yield (g/plant) | Seed yield (t/ha) |
|---|---|---|---|---|---|---|
| 20x50 ($S_{20}$) | 274.18$^{c}$ | 27.42$^{a}$ | 446.06$^{d}$ | 44.61$^{a}$ | 28.39$^{d}$ | 2.84$^{a}$ |
| 40x50 ($S_{40}$) | 392.51$^{b}$ | 19.63$^{b}$ | 987.72$^{c}$ | 49.39$^{a}$ | 56.48$^{c}$ | 2.82$^{a}$ |
| 60x50 ($S_{60}$) | 387.49$^{b}$ | 12.92$^{c}$ | 1538.88$^{b}$ | 51.30$^{a}$ | 93.17$^{b}$ | 3.11$^{a}$ |
| 80x50 ($S_{80}$) | 470.21$^{a}$ | 11.76$^{c}$ | 1922.23$^{a}$ | 48.06$^{a}$ | 117.16$^{a}$ | 2.93$^{a}$ |
| $LSD_{0.05}$ | 64.53 | 3.37 | 185.00 | 7.42 | 11.20 | 0.45 |
| CV (%) | 34.60 | 38.36 | 30.89 | 31.37 | 31.00 | 31.54 |
| F test | *** | *** | *** | Ns | *** | ns |
| **Accession [species, cluster]** | **Leaf yield (g/plant)** | **Leaf yield (t/ha)** | **Berry yield (g/plant)** | **Berry yield (t/ha)** | **Seed yield (g/plant)** | **Seed yield (t/ha)** |
| BG16 [scab, 9] | 629.06$^{a}$ | 27.87$^{a}$ | 2344.66$^{a}$ | 92.68$^{a}$ | 120.41$^{ab}$ | 4.82$^{a}$ |
| BG29 [scab, 10] | 429.26$^{bc}$ | 20.19$^{bc}$ | 1674.52$^{b}$ | 65.95$^{b}$ | 101.70$^{b}$ | 3.97$^{bc}$ |
| IP09 [scab, 8] | 513.06$^{b}$ | 25.00$^{ab}$ | 1078.91$^{c}$ | 42.57$^{c}$ | 75.80$^{c}$ | 2.98$^{de}$ |
| IP12 [scab, 11] | 489.54$^{b}$ | 22.28$^{ab}$ | 1393.79$^{b}$ | 63.74$^{b}$ | 71.02$^{cd}$ | 3.30$^{cd}$ |
| IP20 [scab, 6] | 503.34$^{b}$ | 24.44$^{ab}$ | 2251.71$^{a}$ | 84.19$^{a}$ | 116.69$^{ab}$ | 4.40$^{ab}$ |
| MW04 [tar, 3A] | 321.22$^{cd}$ | 15.60$^{cd}$ | 340.07$^{d}$ | 12.47$^{d}$ | 28.19$^{fg}$ | 1.02$^{f}$ |
| MW12 [gros, 1] | 84.23$^{f}$ | 4.43$^{f}$ | 565.39$^{d}$ | 20.71$^{d}$ | 40.22$^{ef}$ | 1.47$^{f}$ |
| MW13-2 [cf. vill, 2] | 177.21$^{ef}$ | 8.11$^{ef}$ | 367.00$^{d}$ | 14.93$^{d}$ | 20.09$^{g}$ | 0.78$^{f}$ |
| RC01 [amer, 12] | 417.09$^{bc}$ | 20.30$^{bc}$ | 530.24$^{d}$ | 23.60$^{d}$ | 55.88$^{de}$ | 2.40$^{e}$ |
| RC03 [scab, 7] | 345.55$^{cd}$ | 16.07$^{cd}$ | 2499.58$^{a}$ | 93.45$^{a}$ | 127.75$^{a}$ | 4.70$^{ab}$ |
| RC18 [vill, 4] | 282.52$^{de}$ | 12.93$^{de}$ | 413.10$^{d}$ | 17.42$^{d}$ | 54.06$^{de}$ | 2.32$^{e}$ |
| $LSD_{0.05}$ | 107.01 | 5.58 | 306.79 | 12.31 | 18.57 | 0.75 |
| CV (%) | 34.60 | 38.36 | 30.89 | 31.37 | 31.00 | 31.54 |
| F test | *** | *** | *** | *** | *** | *** |
| CV (%) | 34.60 | 38.36 | 30.89 | 31.37 | 31.00 | 31.54 |

ns non-significant; *** p≤0.001; vill=*S. villosum*; cf.vill=cf. *S. villosum*; gross=*S. grossidentatum*; scab=*S. scabrum*; amer=*S. americanum*. Mean separation by Duncan's Multiple Range Test at p≤0.05, values with same letters not significantly different

## SOIL FERTILITY AND PLANT NUTRITION

Application of nitrogen is vital for increased leaf production of African nightshade. It is known that nitrogen deficiency exerts its effects on plant growth through reduced leaf area index and hence low light interception and low dry matter production (Grindlay, 1997). N deficiency leads to reduced photosynthesis resulting in lower biomass accumulation (Zhao et al., 2005). Under limited nitrogen supply, African nightshade plants have been shown to respond by drastic reduction in leaf area (Masinde et al., 2009), as has been shown also in other *Solanum* (Vos and van der Putten, 1998). It has been established that supplying nitrogen can increase leaf yield in African nightshade up to 8-fold depending on the amounts of N applied and the genotypes. Despite the reported results on fertilizer use in literature, growers of African nightshade do not have specific guidelines on the amount of nitrogen to apply. Recent surveys have shown that most farmers in peri-urban areas where production was more market oriented, fertilizers were in use with different amounts being applied. The different amounts of N reported in literature as being optimum for African nightshades could be attributed to differences in agro-ecological zones, water management and disease and pest management. In the absence of specific guidelines, market oriented growers may be tempted to supply high amounts of nitrogen in order to obtain high leaf yields. This may be harmful to the consumers since these vegetables are known to accumulate phytochemicals like phenolics, alkaloids, nitrates and oxalates, whose concentrations may depend on the level of fertilizer use. Nitrate accumulation in the vegetables is a well recognized health hazard to consumers (Taiz and Zeiger, 1998). African nightshades are known to accumulate nitrates (Edmonds and Chweya, 1997). We have found significant increase in leaf nitrate content in African nightshades with increasing nitrogen supply. Excessive application of nitrogen can also lead to environmental contamination.

Working out specific nitrogen use guidelines that consider genotypes and agro-ecological zones is important for good agricultural practices in African nightshade production. The guidelines must include the use of both inorganic and organic sources of nitrogen. Modeling approaches should be incorporated to improve crop nutrition husbandry. Use of empirical models like critical nitrogen concentration curves can be an important tool in nitrogen management (Lemaire et al., 1992). There is need to establish the critical nitrogen concentration curves for African nightshade for optimal nitrogen management. Extensive evaluation of nitrogen requirements in different agro-ecological zones will be necessary to calibrate the curves. This will need to be related to non-destructive simple methods like measurement of SPAD using SPAD meter or leaf colour index. Conventional ways of determining the N demand include determination of N in soil, determining the N in plant (leaf), considering traditional recommendations and nutrient removal guidelines reconciled with soil tests.

Good soil fertility encourages vigorous growth and increased leaf production. Nightshades require large amounts of nutrients and respond positively to increased soil fertility (Edmonds and Chweya, 1997). Well-decomposed poultry, farmyard or compost manure at the rate of 5-10 t/ha should be worked into the soil prior to planting. Where manure is not available, a compound fertilizer such as NPK should be incorporated at the rate of 120-150 kg/ha during sowing/transplanting. N-fertilizers such as urea and ammonium sulphate (60 kgN/ha) are used as top/side dressings after every 2-3 harvests; and foliar sprays are used in commercial production. Although high levels of nitrogen increase yield, they should be used cautiously as this may reduce dry matter content, make plants more susceptible to diseases and cause build-up of nitrates in leaves to toxic levels (Schippers, 2002).

Mwai et al. (2009a) found that the rates of urea up to 120 kg/ha did not produce significant response in leaf yield, but the response of berry and seed yield was significant. Thus, the responsiveness of vegetative and reproductive the yield components in vegetable nightshades to available N was in the order berry yield > seed yield > leaf yield. Thus N fertilizer should

be applied at lower rates (60 kg N/ha) for leaf crops, but higher rates (up to 120 kg N/ha) may be applied to berry and seed crops.

**Table 10: Leaf, berry and seed yield in selected African nightshade accessions in response to N application**

(Source: Mwai, 2007)

| N rate (kg/ha) | Leaf yield (g/plant) | Leaf yield (t/ha) | Berry yield (g/plant) | Berry yield (t/ha) | Seed yield (g/plant) | Seed yield (t/ha) |
|---|---|---|---|---|---|---|
| control ($N_0$) | 359.22[a] | 14.37[a] | 961.55[d] | 38.46[d] | 66.40[c] | 2.66[c] |
| 60 ($N_{60}$) | 336.11[a] | 13.44[a] | 1294.68[c] | 51.79[c] | 85.57[b] | 3.42[b] |
| 90 ($N_{90}$) | 372.55[a] | 14.90[a] | 1526.21[b] | 61.05[b] | 100.71[a] | 4.03[a] |
| 120 ($N_{120}$) | 376.70[a] | 15.07[a] | 1726.79[a] | 69.07[a] | 112.90[a] | 4.52[a] |
| $LSD_{0.05}$ | 57.81 | 2.31 | 178.18 | 7.13 | 12.19 | 0.49 |
| CV (%) | 32.71 | 32.71 | 26.43 | 26.43 | 27.25 | 27.25 |
| F test | ns | ns | *** | *** | *** | *** |
| **Accession [species, cluster]** | **Leaf yield (g/plant)** | **Leaf yield (t/ha)** | **Berry yield (g/plant)** | **Berry yield (t/ha)** | **Seed yield (g/plant)** | **Seed yield (t/ha)** |
| BG16 [scab, 9] | 604.22[a] | 24.17[a] | 2698.90[a] | 107.96[a] | 171.48[a] | 6.86[a] |
| BG29 [scab, 10] | 373.96[c] | 14.96[c] | 1406.81[b] | 56.27[b] | 88.86[bc] | 3.55[bc] |
| IP09 [scab, 8] | 573.35[ab] | 22.93[ab] | 1498.59[b] | 59.94[b] | 106.27[b] | 4.25[b] |
| IP12 [scab, 11] | 384.98[c] | 15.40[c] | 1370.42[b] | 54.81[b] | 84.09[cd] | 3.36[cd] |
| IP20 [scab, 6] | 500.04[b] | 20.00[b] | 2989.81[a] | 119.59[a] | 154.43[a] | 6.18[a] |
| MW04 [tar, 3A] | 240.94[d] | 9.64[d] | 373.09[d] | 14.92[d] | 32.09[g] | 1.28[g] |
| MW12 [gros, 1] | 111.33[e] | 4.45[e] | 724.33[c] | 28.97[c] | 50.06[efg] | 2.00[efg] |
| MW13-2 [cf. vill, 2] | 249.36[d] | 9.97[d] | 328.19[d] | 13.13[d] | 41.84[fg] | 1.67[fg] |
| RC01 [amer, 12] | 313.89[cd] | 12.56[cd] | 494.61[cd] | 19.78[cd] | 64.84[de] | 2.59[de] |
| RC03 [scab, 7] | 341.22[cd] | 13.65[cd] | 2897.54[a] | 115.90[a] | 154.92[a] | 6.20[a] |
| RC18 [vill, 4] | 279.31[cd] | 11.17[cd] | 368.11[d] | 14.72[d] | 56.45[ef] | 2.26[ef] |
| $LSD_{0.05}$ | 95.87 | 3.83 | 295.49 | 11.82 | 20.21 | 0.81 |
| CV (%) | 32.71 | 32.71 | 26.43 | 26.43 | 27.25 | 27.25 |
| F test | *** | *** | *** | *** | *** | *** |

ns non-significant; *** p≤0.001; Mean separation by DMRT at p≤0.05; values with same superscripts not significantly different. vill=*S. villosum*; cf. vill=cf. *S. villosum*; gross=*S. grossidentatum*; scab=*S. scabrum*; amer=*S. americanum*

## WATER MANAGEMENT

African nightshades in Kenya are largely produced under rainfed conditions. Thus production peaks coincide with the long and short rain seasons. These crops are sensitive to drought (Edmonds and Chweya, 1997). We found that leaf expansion and stem elongation for these crops declined significantly when the soil moisture fell below 40-60% of available soil water and that these crops have only limited osmotic adjustment in the range of 0.10-0.33 MPa (Masinde et al., 2005, 2006). In addition, well watered plants had 3-5 fold higher leaf area and up to 45% more dry weight than plants exposed to water deficit. These crops therefore respond to drought mainly by drastic reductions in leaf area and vegetative growth. In addition, soil water deficit has negative effects on the physiological functions of the plant such as transpiration, stomatal conductance and photosynthesis as well as reducing the plant water status that results in low growth as reported in various crops (Sarker et al., 2005; Ferrat-Lazcano and Lovatt, 1999; Monti et al., 2006).

Whereas some leaf production could occur under water deficit, anti-nutrients such as nitrates could also increase. However, it is also likely that the high growth rate in watered plants caused a higher $NO_3$-N assimilation resulting in lower concentrations in the tissues. It is known that when photosynthesis is low, and there is a decrease in plant requirement of protein due to inhibited growth, $NO_3$-N assimilation is also low but not its uptake, hence $NO_3$-N accumulates (Lawlor, 2002). In African nightshade, we have found that mature plants grown under water deficit maintained a higher $NO_3^-$ of 1022 mg/kg compared to 528 mg/kg in well watered plants. These $NO_3^-$ concentrations in mature plants are relatively low compared to levels of upto 3022 mg/kg observed in young well watered plants. Andersen and Nielsen (1992) and Van Der Boon et al. (1990) have outlined the maximum acceptable content of nitrates in lettuce as 3500-4500 mg/kg in Germany and The Netherlands. Maynard et al. (1976) put the fatal dose of nitrates in adult humans at 15 to 70 mg $NO_3$-N per kg body weight (65-304 mg $NO_3^-$ per kg body weight). For infants the fatal dose is less than 10% of that for adults (Maynard and Barker, 1972). Moreover, the acceptable daily intake levels are much lower, at 0-3.65 mg per kg body weight for $NO_3^-$ and 0-0.13 mg per kg body weight for $NO_2^-$ (Santamaria and Elia, 1997). Thus there is always the risk of exceeding the acceptable daily intake levels by consuming leaves from young African nightshades especially if the crop has been exposed to severe water deficit as happens during the dry season.

Irrigation should be recommended for African nightshade production especially during off-season. This should however make use of water-saving irrigation strategies such as deficit irrigation (DI) and partial root drying (PRD) (Kang and Zhang, 2004). Under water saving irrigation, plants generate root signals that cause partial stomatal closure (Sobeih et al., 2004; Liu et al., 2006) and this may maintain high plant water status. Root signals include ABA and inorganic ions like nitrates, $K^+$ and $Ca^{2+}$ (Davies et al., 2002). Sobeih et al. (2004) suggested that exploiting genotype variation in generation of and response to chemical signals in order to maintain leaf growth under soil drying may be a better crop-improvement strategy in leafy crops. There is need to develop appropriate water saving irrigation strategies that will enable affordable production with minimal water input without relying solely on rainfall. Additionally, market oriented growers need to adopt modern ways of soil moisture management through objective methods of soil moisture measurements. This will include use of soil moisture meters.

Use of mulching to improve water use efficiency needs to be stressed for African nightshade. This is done primarily to reduce that rate of evaporation of soil moisture, especially in hot season. Small holder African nightshade growers need to consider mulching as a good agricultural practice. There are various types of mulching materials, both inorganic and organic. Organic materials include leaves, straw, sawdust etc. Inorganic materials include gravel, rockwoll etc. Use of plastic mulches is widespread in the developed countries, but cost may be inhibitive in Kenya.

Because nightshades are not drought tolerant, water is often a limiting factor in their production. It is imperative that soil moisture be adequate throughout the growing period, with frequent irrigation during dry periods. Irrigation frequency should be based on temperature, cloud cover and precipitation. In the absence of rain, mulching is advisable, otherwise daily irrigation is needed for the 1st week after transplanting, but irrigation interval can be reduced after seedling establishment to 2-3 times a week. Watering may be through canals (gravity irrigation) between raised beds or ridges, using a watering can or hose. Overhead irrigation should be avoided due to potential to spread diseases. Frequent weeding is required in the early stages, but once the plants form a canopy, weeds are suppressed (Schippers, 2002).

## HARVESTING, POST-HARVEST HANDLING, PACKAGING, PROCESSING, STORAGE AND RECIPES

Harvesting starts at 4-6 weeks age and the growers harvest by uprooting whole plants or picking young shoots and leaves to about 5 cm, allowing new side shoots to grow. Harvesting frequency may be 7-14 days for long season crops, but complete harvesting by uprooting is done during thinning, or when the crop needs to be cleared to make way for another crop. Harvesting is done the evening before, or very early in the morning and marketed the same day. Minimal or no harvesting of leaves should be done on plants meant for seed production.The type of harvesting is thus important in influencing leaf yield and quality. Additionally, the methods of harvesting may affect the market. For instance, uprooting means the consumer must take time to separate leaves from the stems hence may be inappropriate for the urban busy consumers. There is limited information on these aspects and more research needs to be done. Post-harvest handling at the farm level is non-existent. Farmers reportedly sell out their produce in short periods after harvesting. They hardly experienced any post-harvest losses. The only plausible explanation for this lies in the scale of production. Notably, operating on "kitchen garden"-scales puts no pressure on the producer to preserve, process or even storage. The post-harvest handling aspects by the sellers are not well developed. However, most supermarket retail outlets would always have the vegetable in manageable bundles and kept in relatively cool sections.

Leaves and stem tops are collected from plants in the wild or from fields during the rainy season. Harvesting is normally done in the early morning. The main shoot or side shoots are plucked before flowering, leaving at least 5 cm of stem for the production of new side shoots. This method allows the farmer to harvest 6-8 times from the same plant. The farmer may select some superior plants which are not harvested but left for seed production. The shoots are very tender and therefore highly perishable. The produce is transported in jute bags and, where possible, sold on the same day. Once they arrive at the market, traders sprinkle the leaves with water to keep them fresh. When the product has to be kept for a longer period, it is covered with plastic or banana leaves to protect it from drying. Standard recipes have investigated and reported on (Agong and Masinde, 2003). However, it is known that over cooking destroys most of the essential phytochemicals especially the phenolic compounds which are beneficial in low doses.

## MARKETING SYSTEMS AND LINKING FARMERS TO THE MARKETS

The current marketing channels involve several players, key being middlemen, retail markets, hotels and restaurants and supermarkets. To stimulate increased production and consumption of African nightshade, the marketing systems need to be streamlined. Contract farming is one way of doing this. The growers have to be linked to specific marketing channel through contracts, assuring them of a market for their produce. This has been successfully done in some areas in Kenya through the public-private sector partnerships, in this case, with strong involvement of the NGO sector. This needs to be replicated in the major African nightshade growing areas and should be advanced to include the involvement of the insurance sector to cushion growers from risks. Growers should be group based for greater economies of scale and better production and marketing system control.

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# Good Agricultural Practices for Production of Spiderplant in Sub-Saharan Africa

**Julius Onyango Ochuodho[1], Francis B.O. K'Opondo[2] and Chris O. Ojiewo[3]**

[1]*Moi University, School of Agriculture and Biotechnology, P.O. Box 1125, 30100 Eldoret, Kenya*
[2]*School of Agriculture and Biotechnology, Kabianga University College, P.O. Box 1, 20201 Kabianga, Kenya*
[3]*ICRISAT-Malawi, Chitedze Agricultural Research Station, Box 1096, Lilongwe, Malawi*

**Abstract**

Indigenous leafy vegetables, including *Cleome gynandra* are important as security food crops in sub-Saharan Africa. These vegetables are nutritious and hardy crops that grow easily in relatively poor soils. Increased domestication of these crops should be encouraged and technologies developed to enhance production. *C. gynandra* belongs to the *Capparaceae* family and very close to the mustard family of vegetables. Variety selections, registration and commercialization have been going on but there have not been official variety releases. The seeds of this vegetable germinate readily in darkness at 30°C and like many weedy species develop secondary dormancy shortly after physiological maturity. A limited quantity of seed is produced by seed companies in Kenya and Zambia but most is produced by farmers and there is need to upscale this technology.

## INTRODUCTION

The fast-increasing global population has put enormous pressure on available resources and created not only total food deficits, but also widespread deficiency of micronutrients in developing countries (Graham et al., 2000). Diversification through domestication of locally adaptable wild species of known nutrient quality could be more appropriate. Domestication of indigenous vegetables may progress through a cycle of changing human interests and dependence: from home garden to minor crop, then to major crop and finally to even a broader ecogeographical scope (Bretting and Duvic, 1997). The indigenous African vegetables have the potential to be cultivated, can provide food security and improve the health and living standards of the resource-poor people. There is an increase in acceptance and utilization of indigenous African vegetables in eastern and southern Africa (Fletcher, 1999; Jansen Van Rensburg et al., 2004). These indigenous vegetables can be conserved as seed and preserved by timely planting (Seme et al., 1992). Therefore, information on seed biology and technology of these vegetables is important. Plant breeding and seed production by farmers and private seed companies should be stimulated (Grubben and Almekinders, 1997) in order to reduce the risk of genetic erosion of indigenous vegetables. It has been suggested that studies conducted on *Cleome* should concentrate on production technology packages and post-harvest handling of the crop (Jansen Van Rensburg et al., 2004). National seed companies in Kenya, Senegal, Uganda, Tanzania and Zambia among other countries are producing and marketing seed of indigenous plant species and could make use of information on seed technology. The domestication and improved production of indigenous vegetables could be a step towards self-sufficiency in food production and hence reduce the amount of foreign exchange used in seed importation. However, information on seed technology and production of indigenous vegetables in the region is scarce (Nono-Womdim and Opena, 1997). *Cleome gynandra* is one of these indigenous vegetables used in eastern, central and southern African region.

## BACKGROUND INFORMATION

### Species origins

Spiderplant (*Cleome* or *Gynandropsis* spp.) also commonly known as spider flower plant, African spider flower or cats' whiskers, comprises 150-200 species of which 50 are indigenous to Africa (Schippers, 2002). Edible and neglected species include *C. allamani*, *C. hirta* (Klotzsch) Oliv., *C. gynandra* L. Chiov, *C. monophylla* L., *C. rutidosperma* DC, and *C. viscosa* L. *Cleome gynandra* (L.) belongs to the family *Capparaceae* of the order *Capparale*s (Porter, 1967; Cronquist, 1988).

*Cleome gynandra* is widespread in the tropics as a weed and it probably originated in southern Asia, Africa or Central America (Mnzava and Ngwerume, 2004; Chweya and Mnzava, 1997; Fletcher, 1999). *C. gynandra* is the most common type of spiderplant occurring throughout all countries of tropical Africa. It is mainly found near human settlements, possibly as escapes from earlier introductions. For years it has been a semi-domesticated volunteer crop in home gardens in many parts of sub-Saharan Africa where its leaves are eaten as spinach, but in the recent past, it has been cultivated as a commercial crop, mainly in Kenya and South Africa. It is used as both food and medicine (Venter et al., 2000; Nesamvuni et al., 2001). Plant extracts of *C. gynandra* were found to be heat stable and fungitoxic (Pandey et al., 1993) and its essential oils exhibited good repellence against the livestock tick (Lwande et al., 1999). It was recently noted by Jansen Van Rensburg et al. (2004) that indigenous leafy vegetables, which are rich in micronutrients and vitamins, could play an important role in alleviating hunger and malnutrition in sub-Saharan Africa.

Spiderplant occurs from sea level up to 2400 m asl and requires warm conditions; growth is hampered below 15°C. It is less common in very humid areas. It is generally sensitive to water stress, causing early maturity and senescence. It is insensitive to daylength. Spiderplant is found on a wide range of soils, mostly on sandy to clay loam, provided they are deep and well drained with pH 5.5-7.0. It prefers soils with high organic matter and adequate mineral reserves. It occurs as wild, semi-wild or as weedy forms in crops on fertile well-manured soils.

### Seed dormancy and germination of *Cleome*

Börhinger et al. (1999) observed that the seeds of *Cleome gynandra* showed dormancy for up to 6 months after harvest, as had been stated by Chweya and Mnzava (1997). A study investigating the effects of temperature and light on seed germination of *C. gynandra* (Börhinger et al., 1999) did not produce conclusive results but described the cardinal temperatures for seed germination. However, Ochuodho and Modi (2007) showed that mature seeds from green maturing pods attained over 90% germination and noted that the species acquired secondary dormancy immediately after physiological maturity. *Cleome* seeds responded negatively to continuous white light during germination at 20°C (Ochuodho and Modi, 2007). This photoinhibition was more evident in seeds harvested when the pods had turned brown than the mature black seeds selected from green pods. This suggests that *C. gynandra* does not exhibit primary dormancy but can show secondary dormancy as observed in figure 33.

The seed germination of *Cleome gynandra* is negatively photoblastic and should be germinated at alternating temperatures of 20/30°C or at 30°C in darkness (Ochuodho, 2005). The non-dormant seeds germinate well between 20°C and 30°C in the dark without pre-treatment, while germination of the dormant seed was improved by pricking at the radicle end. Longer light exposures, more than 12 h per day, can drastically reduce seed germination or even inhibit it at sub-optimal temperatures due to photo-inhibition. The germination of

photo-inhibited seeds was improved when the seeds were pre-treated with $GA_3$. Chilling, pre-hydration and priming with $KNO_3$ did not effectively improve germination percentage.

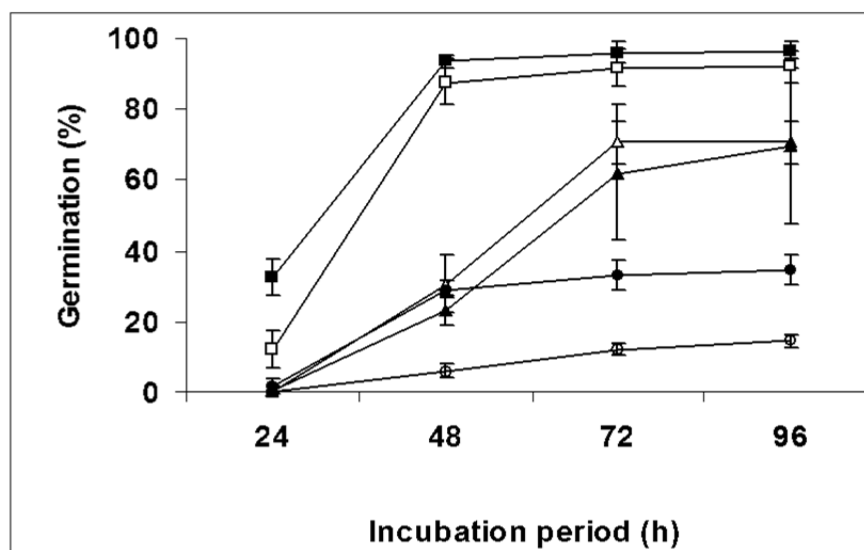


**Figure 33: Germination of black seeds of *Cleome* grown in the field and harvested from green pods incubated at alternating 20/30°C (16 h night/8 h day) in continuous white light (□) or darkness (■), yellow pods incubated at 20/30°C in continuous white light (△) or in darkness (▲) and brown pods incubated at 20/30°C in continuous white light (○) or in darkness (●). Error bars represent SD, n = 4.**

## BREEDING AND GENETIC RESOURCES

The spiderplant is thought to have originated in tropical Africa and Southeast Asia, and have spread to other tropical and subtropical countries in the northern and southern hemispheres (Kokwaro, 1976). It is widely distributed in many parts of the tropics and subtropics, including countries in Asia and the Americas (Mnzava and Chigumira, 2004; Chweya and Mnzava, 1997; Waithaka and Chweya, 1991). It grows as a weed and also semi-cultivated as an indigenous leafy vegetable in some areas. These countries could therefore constitute important centres of diversity. Other than local landraces, there are no known described botanical varieties or cultivars. However, there are phenotypic variations among plant population which include such traits like stem and petiole length and pigmentation, plant height, number of leaflets per compound leaf and their shapes, pubescence on stems and leaves and number of days to flowering (K'Opondo, 2009; Schippers, 2000; Maundu et al., 1999; Chweya and Mnzava, 1997; Kemei et al., 1995; Omondi and Ayiecho, 1992). Molecular studies conducted on four selected similar plant morphotypes collected from western Kenya confirmed genetic variation (K'Opondo, 2009). However, there was no significant difference between seed storage proteins extracted from similar morphotypes (Ochuodho, 2005).

There is significant variation among plant populations for many characteristics. Clearly different populations can be found in the coastal regions of Kenya and Tanzania, with relatively small plants that are much branched and have distinctly dark, almost black, straight and stiff pods. They appear to be very different from plants encountered elsewhere in Africa, where the fruits are less stiff and often green or yellow to pale brown. The focus of genetic improvement is on higher leaf yield, plant uniformity, longer vegetative phase and drought tolerance.

## PRODUCTION

Indigenous leafy vegetables, including *Cleome gynandra* are important sources of micronutrients and can play an important role in alleviating hunger and malnutrition in sub-Saharan Africa (Jansen Van Rensburg et al., 2004).When domesticated they require few inputs and tend to grow and produce in areas where cultivation of exotic vegetables is difficult. These vegetables are grown by women in small plots or at times interspersed with other food crops. Production is still largely at subsistence level with a few farmers going commercial to feed urban centres. Little fertilization is done although research has shown that there is improved yield and leaf quality when fertilizers are used (Venter et al., 2000; Abukutsa-Onyango, 2007; K'Opondo, 2009).

### Climatic requirements

The species is adapted to a wide range of environmental conditions. It grows well from 0-2400 m above sea level (Maundu et al., 1999), tolerating high and low temperatures, but thriving best from 18-25°C; growth is hampered at below 15°C. Spiderplant can tolerate some drought conditions, but water stress tends to hasten maturity and senescence of the plants, and also reduces leaf yield and quality (Mnzava and Chigumira, 2004; Schippers, 2000). It requires soils with high organic matter content, with adequate mineral reserves (Mnzava and Chigumira, 2004). For rapid growth rate and high leaf yields and quality, nitrogen is particularly important. Plants grow on a wide range of soils, but these should be deep and well drained, with a pH range of 5.5-7.0. Throughout its growth period, spiderplant therefore requires plentiful supply of soil moisture, although it cannot withstand waterlogging or flooding (Fletcher, 1999; Waithaka and Chweya, 1991). Spiderplant responds well to well-decomposed farmyard or compost manures, and flowering is delayed when adequate manure is available, thus allowing more and larger leaves to be harvested (www.infonet-biovision.org-spiderplant; AVRDC, 2003; Chweya and Mnzava, 1997; Waswa et al., 1996). Optimum yields could be obtained with an application of 20-30 tons of manure per hectare (AVRDC, 2003; Schippers, 2000; Waithaka and Chweya, 1991). When manure is not available, inorganic fertilizers can be used. At planting apply 200 kg of Diamonnium Phosphate (DAP) per hectare (Waithaka and Chweya, 1991) and after thinning at 3-4 weeks top-dress with 100 kg Calcium Ammonium Nitrate (CAN) per hectare (Mnzava and Chigumira, 2004; Waithaka and Chweya, 1991). Both organic and inorganic sources of fertilizer significantly increase yields of edible portions of spiderplant (Abukutsa-Onyango, 2007). Combinations of both organic and inorganic fertilizers can be used. Seed yield has been found not to be responsive to nitrogen application. At higher nitrogen rates, stems tend to become too succulent and regeneration capacity is reduced, which is a disadvantage where plants are harvested periodically.

### Crop agronomy

Plants require a thoroughly prepared seedbed to a depth of 15 cm of fine tilth. Organic manure is applied and worked into the soil. Direct sowing is the norm, and it is done at the onset of the rains. Seeds are either broadcast or drilled in rows, which are spaced about 20-30 cm apart. Farmers who grow the crop under irrigation prefer to sow spiderplant in rows spaced 50-cm apart, thinning plants three weeks after emergence to about 15 cm within the row. The recommended spacing is 30-50 cm between rows and 15-20 cm within rows (Oluoch et al., 2009). In order to avoid uneven seedling emergence and poor stand establishment shallow seeding in drills of depths of $\leq$ 1 cm is recommended. Seed requirement is about 4 g of seed per $m^2$ (about 40 kg/ha). Seed germination takes place after 4-5 days, with seedling emergence after 6-8 days. Germination can be rather uneven when some of the seeds are dormant. Topping and removing inflorescences as soon as they appear are other practices that increase leaf production for harvesting.

Application of about 90 kg urea (41.4 kg N/ha), combined with 25 cm spacing, was reported to be optimum for production of high economic yields (AVRDC, 2001). The spacing of 25 cm was also reported to give the highest leaf yield (fresh weight), dry matter, seed yields and 100-seed weight (AVRDC, 2002). Further studies at AVRDC recommended that spiderplant be grown at a spacing of 25 × 70 cm in double rows on raised beds (AVRDC, 2003). However later studies showed that spiderplant could perform even better at a spacing of 20 cm between plants (AVRDC, 2004).

Weeding is a must because spiderplants do not have dense foliage and they cannot compete with weeds. The plants can be attacked by the following pests: flea beetles (*Phylloptreta mashonana* Jac.), which chew away at the margins of the leaves making the products less attractive for human consumption; pentatomids/bugs (*Acrosternum gramineum* and *Agonoselis nublis*) and their parasitoids; locusts (*Schistocera gregaria*); aphids; nematodes; green vegetable bugs (*Nezara* spp.); cabbage sawfly (*Athalia* spp.); cotton jassids (*Empoasca* spp.); hurricane bugs (*Bagrada* spp.) and stem borers. Weaver birds (*Quelea quelea*) eat young seeds. In Botswana, tortoises have been reported to enjoy eating spiderplants (Schippers, 2000; Chweya and Mnzava, 1997).

Diseases recorded for spiderplant include mildew fungus (powdery mildews *Sphaerotheca fuliginea*, *Oidiopsis taurica* and *Cercospora uramensis*) (Chweya and Mnzava, 1997) and Fusarium root rot. Pests and diseases are not usually serious and spraying with insecticides is not recommended even when aphids appear to become problematic (AVRDC, 2003). However, as domestication and production increases with the development of more palatable varieties more pests and diseases will be reported.

**Harvesting**

The spiderplant may start flowering as early as one month after germination and thinnings can be used as vegetables. The first harvest should take place before the flowers open. When plants reach a height of about 15 cm they can be harvested once by uprooting whole plants, or by topping (pinching/deflowering) or cutting back to 10 cm of the base (ratooning), or picking individual leaves or leafy branches at frequent intervals, to encourage lateral growths, which will provide successive harvests. Deflowering, cutting back or frequent harvesting, also delay flowering, thus extending the harvesting period (Oluoch et al., 2009). Harvesting tender stems, leaves and flowers gives significantly higher mean economic leaf yields (150 g/plant) than other harvesting methods.

Harvesting starts 4-6 weeks after seedling emergence and may last 4-5 weeks. When tender leaves are removed biweekly, this practice allows for regeneration of branches. Leaf yields as high as 19 t/ha have been realized with application of manure or inorganic fertilizers (Waithaka and Chweya, 1991). Chweya and Mnzava (1997) noted a cumulative yield of about 30 t/ha per season of young shoots and up to 500 kg of seeds. Potential exists to increase leaf yields up to 40 t/ha, from four successive harvests where high amounts of manure are applied to the plants and coupled with improved cultural practices (Waithaka and Chweya, 1991).

Weekly leaf yields have been observed to increase with age, until about the 7$^{th}$ week of growth, when they start declining. By the 10$^{th}$ week of growth, the yields would have decreased by about 90%. Old plants tend to produce small and bitter leaves (Mnzava and Chigumira, 2004; Chweya and Mnzava, 1997). After harvesting several times the remaining plant will flower and the silique will take time to mature and dry properly (3-4 months) at the end of which seeds are shattered through dehiscence. In order to obtain good quality seeds the silique should be picked just as they begin turning yellow, before they are fully ripe, and should be dried in a cool controlled condition (Ochuodho, 2005; Schippers, 2000).

*Cleome gynandra* is a versatile crop with many uses and can grow in relatively poor soils. There are four types identified up to the molecular level and the germination of seeds has been shown to be negatively photosensitive. Many authors note that the seeds have some dormancy but this must be due to late harvesting time. Seed selection on the basis of seed coat colour and timely harvest coupled with proper handling can improve seed quality.

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# Good Horticultural Practices of Vegetable Cowpea in Sub-Saharan Africa

**P.M. Kusolwa[1], G.M. Tryphone[1], T. Herman[1], J.E. Mosile[1] and C. Ojiewo[2]**

[1]*Department of Crop Science and Production, Sokoine University of Agriculture, P.O. Box 3005, Morogoro, Tanzania*
[2]*ICRISAT-Malawi, Chitedze Agricultural Research Station, Box 1096, Lilongwe, Malawi*

**Abstract**

Cowpea (*Vigna unguiculata* [L.] Walp.) is indigenous to several countries in sub-Saharan Africa and has been cultivated for a long time as an important grain legume in sub-Saharan Africa. It is also an important pulse legume whose fresh pods and leaves can be harvested for vegetable use. The mature pods can be used as fresh pods and/or dry pulses as important source of protein in daily diets of most people in the rural and urban communities. The cowpea leaves and green pods can be eaten, providing an important food source, and act as a food bridge during the 'hunger gap' between harvests. The countries in sub-Saharan Africa accommodate a great diversity of cowpeas species and cultivars that are used as fresh pods, pulses and green leafy vegetables over different market groups. Although sufficient genetic variation is available for successful development of cultivars for both leaf and seed or leaf production only, breeding work for cowpea as leafy vegetable is still very limited. This article discusses some of the general and specific horticultural practices of vegetable cowpeas in Africa and associated genetic improvement efforts and demonstrates opportunities for future perspectives of cowpeas improvement in the region.

## INTRODUCTION

Cowpea (*Vigna unguiculata* [L.] Walp.) is indigenous to several countries in Africa and has been cultivated for a long time as an important grain legume in sub-Saharan Africa. Cowpea belongs to the family *Fabaceae* and genus *Vigna*. All cultivated cowpeas are grouped under the species *Vigna unguiculata*. It is a staple food and an important source of protein for over 200 million people in sub-Saharan Africa.

Numerous varieties that are prostrate with long vines are used for their leaves and in many places the crop is the vegetable of major importance (Schippers, 2002). Cowpea grain, which is valued for its high nutritive quality and short cooking time, serves as a major source of protein in the daily diets of the rural and urban poor in the region. Pulse cowpeas provide about 23% protein, 1.3% fat, 1.8% fiber, 67% carbohydrate and water content of 8-9% (National Research Council, 2006). Singh et al. (1997) revealed that grain is considered nutritious as 100 g dry weight of it contains 23.5 mg proteins, 1.3 mg fat, 60.0 mg carbohydrate, 10.6 mg fibre, 110 mg Ca, 184 mg Mg, 424 mg P, 8.3 mg Fe, 3.4 mg Zn, 50 IU vitamin A, 0.85 mg thiamin, 0.23 mg riboflavin, 2.1 mg niacin, 0.36 mg vitamin B6, 633 μg folate, and 1.5 mg ascorbic acid. Cowpea seeds both fresh and dry are low in antinutritional components such as lectin and trypsin inhibitors, making it a crop with a tremendous potential to contribute to the alleviation of malnutrition among resource-poor farmers. It is mostly grown in west Africa on an area of more than 7 million hectares. Cowpea has been used in this part of the world for many hundreds of years. It is regarded as drought tolerant due to its deep rooting system and can cope with poor soils, making it highly adapted to the region. It is usually grown as an intercrop with the major cereals, namely millet and sorghum.

Rural families in sub-Saharan Africa grow cowpeas for sale, for their own consumption and feeding animals on the husk of the bean. One advantage of cowpeas compared to many other legumes is that the leaves and green pods can be eaten before crop maturity. This provides an important food source before cowpeas are harvested and acts as a food bridge during the 'hunger gap' between harvests in most rural farming communities. Despite their significant role in food provision, many of these locally and regionally important crops are neglected in research and development.

## DISTRIBUTION AND DIVERSITY OF COWPEA

The center of origin and domestication of *V. unguiculata* is Africa, where a large genetic diversity of wild types occurs throughout the continent, mostly in southern Africa (Angessa, 2006). It has been introduced in Madagascar and other Indian Ocean islands, where it is sometimes found as an escape from cultivation. The greatest genetic diversity of cultivated cowpea is found in west Africa, in the savanna region of Burkina Faso, Ghana, Togo, Benin, Niger, Nigeria and Cameroon. Cowpea is the most important pulse crop in the savanna regions of west, central, east and southern Africa, where it is an important vegetable and a valuable source of fodder (Angessa, 2006; National Research Council, 2006).

*Vigna* comprises about 80 species and occurs throughout the tropics. *V. unguiculata* is extremely variable, both in wild and cultivated plants. Up to 10 subspecies have been distinguished. In cultivated types, *V. unguiculata*, two main groups of growing habits are prostrate or indeterminate type and erect or determinate type. These two types differ from one another on a number of traits such as seed size and color, time to maturity, yield and taste. The indeterminate or spreading group has both early and late-maturing types with large and small seeds, while determinate types are generally early maturing with small leaves and seeds (Nkongolo, 2003). The indeterminate and spreading types or cultivars provide high dry matter output per unit area for leafy vegetables.

Keding et al. (2007) reported for Tanzania that the prostrate types mature in a period of 140 days, allowing repeated leaf picking without compromising seed yield, while the erect types take about 80 days to mature, and leaf picking clearly affects seed yield. In Malawi, the prostrate or indeterminate types are grown for subsistence farming with grain and leaves being harvested while, on the other hand, the erect or determinate types are in most cases suitable for commercial farming in monocropping systems with mainly grain being harvested (Nkongolo, 2003).

Apart from this grouping, *V. unguiculata* can be subdivided into five cultivar groups (Singh et al., 1997; Reis and Frederico, 2001). Unguiculata (common cowpea) consists of pulse and vegetable types, grown for the dry or immature seeds, young pods or leaves. Biflora (catjang cowpea) consists of cowpea grown for seeds, tender green pods and fodder. Sesquipedalis (yard-long bean), also known as *Dolichos sesquipedalis* L. or *V. sesquipedalis* (L.) Fruhw, is grown for the young pods. Textilis is a small group only grown in Nigeria for the fibre extracted from the long peduncles. Cultivar group Melanophthalmus includes "blackeye pea" type cowpea with large, somewhat elongated seeds with wrinkled seed coats and fragile pods.

## USES OF COWPEA

Cowpea is appreciated as a leafy vegetable in many parts of eastern and southern Africa and also Asia, where leaf is the major final product (Saidi et al., 2007). For instance, in many parts of Africa, cowpea is among the most important leafy vegetables (Barrett, 1990). Cowpea can be consumed at different stages in its development. Various products (young shoots, young leaves, young pods, immature seeds, mature seeds and sprouts) of different legume species and cultivars are consumed in diverse ways. Immature seeds and the immature seed pods are boiled and eaten as a vegetable. Most cowpeas are cooked with vegetables, spices and palm

oil to produce a thick soup that accompanies the basic staple. The seeds are also decorticated, ground into flour, mixed with chopped onion and spices, and pressed into cakes that are either deep-fried or steamed (National Research Council, 2006).

## AGRONOMY OF COWPEAS AND PLANT NUTRITION

### Sowing

In many parts of Africa, cowpea seeds are sown by broadcasting, either in monoculture or mixed with cereal crops or in plantations of coffee or banana. There are cases of line sowing with spacing of 75 cm between rows and 10 cm within the row. To achieve a higher plant population, narrow rows of 30 to 50 cm have been used in commercial plantings. Seed should be planted 2 to 2.5 cm deep, and good seed soil contact is important. Optimum plant spacing depends on vine type. Determinate types may be planted 5 to 7.5 cm apart, while indeterminate types require more space (Davis et al., 1991).

### Fertilizer application

Cowpea, like other legumes, forms a symbiotic relationship with specific soil bacteria (*Bradyrhizobium* sp.) that make atmospheric nitrogen available to the plant by the process of nitrogen fixation (Davis et al., 1991) that occurs in the root nodules as the bacteria utilize sugars produced by the plant. Legumes have high P requirements for nodule development and optimal plant growth (Mulongoy, 1985). Although cowpea rhizobium is normally widespread, seed inoculation with a rhizobium strain specific to cowpea would be beneficial in areas where it is not present. In cases where the soil nitrogen is too low, a limited amount of nitrogen (starter nitrogen) should be applied to support the initial stages of crop and nodule development for N fixation. Excess nitrogen (N) should be avoided because it promotes lush vegetative growth, delays maturity, may reduce seed yield, may suppress nitrogen fixation, and may make the plants more susceptible to pest and disease attacks (Davis et al., 1991).

### Cropping systems

Cowpeas are usually grown as an intercrop with the major cereal including sorghum, maize and millet. The principal reasons for farmers to intercrop are flexibility, profit maximization, risk minimization, soil conservation and maintenance, weed control, and nutritional advantages. The soils in semi-arid sub-Saharan Africa are inherently low in nitrogen and phosphorus. Proper management of soils and organic amendments such as crop residues and manure, which are essential complements to mineral phosphorus fertilizers, can increase yields of cowpea and associated cereals more than threefold. Indeed, cowpea has been called a nearly perfect match for the African soil, weather and people. Cowpea fixes atmospheric nitrogen, thus lifting the nitrogen content in the land around it. Direct application of indigenous phosphate rocks can be an economical alternative to the use of imported more expensive soluble phosphorus fertilizers for cowpea production in the region.

Where soil degradation is a major constraint to crop production, inclusion of cowpea to the cropping system is crucial as it helps to replenish soil nitrogen. Cowpea rotation is an effective resource management technology in cereal based systems since some of the nitrogen requirement of cereals can be met by cowpea rotation and intercropping. Studies on cereal cowpea rotation revealed that yields of cereals succeeding cowpea could, in some cases, double compared to continuous cereal cultivation. With efficient soil fertility management, cowpea can fix up to 88 kg N/ha and this results in an increase of nitrogen use efficiency on the succeeding cereal crop from 20% in the continuous cereal monoculture to 28% when cereals are in rotation with cowpea. Furthermore, the use of soil nitrogen increased from 39 kg N/ha in the continuous cereal monoculture to 62 kg N/ha in the rotation systems (Bationo et al., 2000). Cowpeas also contribute to the sustainability of cropping systems and soil

fertility improvement on marginal lands through provision of ground cover and plant residues (which minimize erosion and subsequent land deterioration), nitrogen fixation, increasing soil fertility and suppressing weeds.

**Irrigation**

Cowpea can withstand considerable drought and a moderate amount of shade, but is less tolerant to water logging. Despite its drought tolerance, it requires sufficient water supply for satisfactory yield and quality of the product. Good horticultural or agricultural practices should also associate with finding solutions of water scarcity to cowpeas. Methods under which water shortage can be overcome include water harvesting from shallow wells and use of irrigation. Alternatively water conservation through improved water-holding capacity of the soils can be practiced by addition of organic materials and options for soil cover to minimize evaporation and surface run-offs. One way to assuage water stress is to increase water-holding capacity with organic fertilizers that would increase availability and efficacy of water. Drought reduces both N fixation and the extent to which plants depend on fixed N for their total N supplies.

Cowpea water requirement depends on the crop duration in the field. Cowpea has a wide range of adaptation in the sub-Saharan tropics from short-duration cultivars in semi-arid regions through sub humid to the humid forest belts. Cowpea can produce good seed yield (1600-3000 kg/ha) without fertilizer application or irrigation, but with all major pests controlled (Rachie, 1985). The crop needs adequate water for only 55 days (65%) of its life. Water logging should be avoided throughout crop growth as it will impede nodulation and reduce yields significantly.

**Harvesting**

In east and west Africa, many rural households are reported to have few rows of cowpea for leaf picking, where later on the seeds are harvested from the same plants (Ahenkora et al., 1998). In two villages studied in Malawi, farmers usually remove early flower buds in order to stimulate leaf production (Malidadi, 2006). If seeds are desired, leaf harvesting should stop before pods enlarge (Barrett, 1990). Early leaf harvest (20 days) produced the highest shoot harvest indices and good yield (Ohler et al., 1996). Within limits, cowpea leaves could be harvested without adversely affecting seed yield (Akundabweni et al., 1989). On the contrary, even a limited harvest of leaves during vegetative growth has been found to have a detrimental effect on seed yield of cowpea harvested from the same plants afterwards (Bubenheim et al., 1990). In another study, leaf harvesting reduced both number of pods and seed yield (Tolera, 2006).

Depending on temperature and market demand, cowpeas are ready for harvest 16 to 17 days after bloom or 60 to 90 days after planting. The threshold level at which combined leaf and seed yields is highest has been reported to be achieved when leaf harvesting starts 30 days after planting with harvesting frequency as per leaf appearance (Rwegasira, 2009).

Harvesting of cowpea can be done mechanically or by hand. Harvesting of cowpeas by hand is recommended as hand harvested cowpeas suffer less damage and the harvest season may continue over a one or three week period. Cowpeas can be harvested in three different stages of maturity depending on market demand such as, green snaps, green mature and dry grains.

Leaf harvesting could delay flowering and therefore delay seed harvest. The grain yield is also affected by leaf picking in determinate varieties. But cowpea grains are harvested when pods mature and fodder is harvested later as the leaves start changing color. Cowpea fodder is fed to livestock or sold by farmers for additional income. The roots should be left in the soil

and allowed to decay so that they can contribute to fertility of the soil, which could benefit the succeeding crop.

**Post-harvest handling**

Cowpea leaves are most commonly served boiled to accompany a starchy stiff porridge, but are also consumed fried or fresh in relish. Cooking before drying of cowpea leaves is a widespread method of preservation (Bittenbender, 1992). For example in some African countries, boiled cowpea leaves are kneaded to a pulp and then squeezed into golf-ball-sized pellets that are dried in the sun and stored (Bittenbender et al., 1984). Dried cowpea leaves are sometimes ground into a powder, and stored for use in the dry season when fresh leaves are not available (Bittenbender et al., 1984). Canning techniques have been developed for cowpea leaves (Imungi and Potter, 1983). Cowpea leaves, dried or fresh, are sold commonly in local and urban markets whenever available (Bittenbender et al., 1984).

Vegetable cowpeas from both leaves and fresh pods require similar strategies for storage in order to enhance their shelf life in the market. Once harvested, the leaves need cool conditions to minimize the respiration rates. Therefore a cool chain is necessary for keeping up with good quality produce. Fresh produce can be kept under shelf for 3-5 days at 4-10°C maintained under high relative humidity facilitated by mist spray of cold water to minimize water loss of foliage. Green pods are packaged in bundles or loose in buckets and stored under cool temperature and are normally sold directly as fresh pods or shelled and the fresh seeds sold. For longer storage and preservation the fresh leaves can be blanched and canned or can be dried for future use. Dried blanched leaves are normally mixed with dried onions, pepper and dried tomato for spicing up. In this way they can be kept longer by households. The vegetable cowpeas business is almost 100% controlled by women from the production to the entire value chain of the product to marketing.

**Pollination, breeding and genetic resources**

Cowpea is a botanically self-pollinated crop whose flowers open in the morning, close before noon and fall off the same day. In dry climates cowpea is almost entirely self-pollinated, but in areas with high air humidity there may be about 40% out-crossing. The length of the reproductive period is very variable, with the earliest cultivars taking 30 days from planting to flowering, and less than 60 days to mature seeds. Late cultivars with indeterminate growth take 90-100 days to flower and up to 240 days for the last pods to mature.

The world average seed yield of dry cowpea seed is low though yield potential of 3 tons/ha of seed can be achieved with good management and use of improved varieties. Even with their high nutritional quality, their utilization as vegetable since ages by local societies, and their co-evolution as locally important crops together with complex farming systems, little research has been conducted and, hence, poor achievements have been made for African legumes as vegetables. As a result, available diversity should be researched and promoted in order to develop improved cultivars, though breeding for advanced genotypes has an adverse effect on the genetic diversity. Therefore, appropriate conservation mechanisms also need to be established in order to conserve the germplasm and important traits to meet the need of future generations. There is need for more drought-tolerant and more nutritious crops. Developing new methods of production, new gene combinations, and new basic knowledge would benefit farmers while building new momentum for a largely forgotten global crop (cowpea). The breeding programmes should focus on developing cultivars that are resistant to insects (both in field and storage) and diseases and drought tolerant.

**Production constraints and crop improvement**

There are a number of biotic and abiotic constraints to sustainable cowpea production. Susceptibility to a number of insect pests and diseases is an important factor hindering a

sustainable vegetable cowpea production. Proper timing is critical to circumvent the limiting factors during critical growing periods. For instance, the effect of severe drought in relation to phenology and high night temperatures as it affects flowering, pod and seed development are pointed out as among key cowpea production constraints (Padi, 2004). Although sufficient genetic variation is available for successful development of cultivars for both leaf and seed or leaf production only (Bittenbender et al., 1984), breeding work for cowpea as a leafy vegetable is still very limited, rather the focus has been more on grain yield improvement (Bittenbender et al., 1984; Keller et al., 2005; Keding et al., 2007).

Much work has been done on *V. unguiculata* breeding, mostly for cultivars grown as a pulse, and in Southeast Asia for yard-long bean. Selection criteria for cowpea concern tolerance/resistance to biotic and abiotic stresses, plant type, seed type and yield adaptability. To minimize the adverse effects of environmental stresses on yield, plant breeders have made attempts to produce cultivars that would perform reliably well across a range of sites and years (Helland and Holland, 2001). Unfortunately, however, most variety trials are conducted in relatively common environments and with relatively homogeneous varieties (Borgen, 2006). Cultivars with wide environmental adaptation help to buffer farmers from crop failures (Erskine, 1977) due to interaction with the environment (Hackett et al., 2006).

Improved cultivars with resistances to various biotic factors, such as bacterial blight, cowpea aphid-borne mosaic potyvirus, cowpea aphids, cowpea curculio, root-knot nematodes, cowpea weevil and parasitic weeds, have also been developed for pod production, fodder and for intercropping. These cultivars are often short, erect, determinate types selected for optimal dry seed production but are unsuitable as leafy vegetables. Breeding work on African vegetable cowpea types is still limited. Simlaw Seed Company (Kenya) has commercialized ‘Kenduke-1’, a semi-trailing type selected for large leaves with an attractive green colour and good taste and that can be picked for a long time. In collaboration with AVRDC, the company recently released another variety, ‘Tumaini’. Future improvement relies on the collection of landraces and their wild relatives and their incorporation into breeding programmes. Fortunately, wild African *Vigna* species successfully cross with *V. unguiculata*.

Apart from traditional dual-purpose cowpea cultivars, harvested as pulse and for the leaves, there is need for special vegetable types. As leafy vegetable dwarf plants with erect or prostrate habit, long vegetative period, tender shoots and many broad leaves are desirable, provided the tastes are acceptable. For immature seed, dwarf plants with erect or prostrate, determinate habit may be suitable. For fresh pods, pods about the size of French bean (15 cm long) are desirable in hot lowland regions.

## CONCLUSIONS

Any horticultural or agronomic practices that will result into increase in productivity of the vegetative growth as well as production of fresh pods or enhanced pod set and seed development will increase productivity of the crop. In order to increase the production of vegetative growth proper management through increased supply of nitrogenous fertilizers in form of manures and inorganic fertilizers is needed at different times of crop development. Uniform and regular water supply to the crops in the field to minimize stress will favor the development of vegetative flush. Harvesting techniques or alternatively called pre-harvesting will act as pruning to the crop thus encouraging production of new vegetative shoots that can be a yield enhancement of vegetable leafy cowpeas. Enhanced supply of potassium and nitrogenous source to the soil will have a positive influence on pod formation and pod sets that can be useful in the production of fresh pods as vegetables. Proper planning for timing of the concision of a reliably cool season will enhance pod set and development as well as good pollination.

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# Good Agricultural Practices for the Production of Underutilized Vegetables in Sub-Saharan Africa: Case of Amaranth (*Amaranthus* spp.) in Côte d'Ivoire

**Lassina Fondio[1]*, Jean Claude N'zi[1], Edith Adouko Agbo[2], Adolphe Mahyao[3], Hortense Andé Djidji[1] and Mako François De Paul N'Gbesso[1]**

[1]*CNRA/Vegetables and Proteagineous Crops Research Program, 01 BP 1740 Abidjan 01, Côte d'Ivoire*
[2]*Université d'Abobo-Adjamé, UFR Sciences et Technologie des Aliment, 02 BP 801 Abidjan 02, Côte d'Ivoire*
[3]*CNRA/Land System and Sustainable Development Program, BP 602 Gagnoa, Côte d'Ivoire*
**Corresponding author (lfondio@yahoo.fr)*

**Abstract**

Amaranth (*Amaranthus cruentus*) or Brom-brou (local name) is an important African leafy vegetable in Côte d'Ivoire where it is produced in the whole country but mainly in the urban areas. Farmers usually grow their own traditional cultivars which are not improved. In order to establish a breeding program, about 18 accessions were collected. Agromorphological characterization of this germplasm is on-going. Farmers do not use the right nursery management practices. Amaranth requires large amounts of nitrogen and other nutrients and therefore does well in soils that are rich in organic matter. The number of branches per plot and leaf yield differs significantly according to the amount of manure applied. Zero fertilisation produced fewer branches and lower leaf yield compared to manure-treated plots. The production system comprises both monocropping and mixed cropping. But the current practice is the association of amaranths with lettuce and chive (*Allium schoenoprasum*) culture. In this system, amaranth is planted around the bed of the main crop. The majority of farmers harvest amaranth by cutting leaves and stem regularly. As for post-harvest management, amaranth is directly sold at markets or consumed without any transformation. Preservation practices are uncommon. It is transported from field to market in bags. Producers sell their products directly to retailers or wholesalers. On rare occasions, farmers go directly to the market without any intermediary. From the perspective of promoting this traditional leafy vegetable, it is necessary to establish an appropriate research programme for amaranth to develop improved varieties, develop good cultural practices and post-harvest management systems (preservation, packaging, transformation, marketing, etc.).

**Keywords:** amaranth, breeding, germplasm, crop management, market, post-harvest managements, promoting

## INTRODUCTION

Amaranth (*Amaranthus cruentus*) or brom-brou (local name) is an important indigenous leafy vegetable in Côte d'Ivoire where it is produced by more than 65% of the urban vegetable producers. It is the most popular of the six main indigenous leafy vegetables grown in the country: amaranth (*Amaranthus* spp.), jute mallow (*Corchorus* spp.), roselle (*Hibiscus sabdarrifa*), Lagos spinach (*Celosia argentea*), spinach (*Basela alba*) and spiderplant (*Cleome gynandra*). With the increasing growth rate of the population (more than 3% per year in Côte d'Ivoire), food and nutritional security are becoming fundamental livelihood issues for Ivorian agriculture. During the last few years, the National Agricultural Research Centre

(CNRA) has conducted studies with the aim of improving current cultural practices and thereby contribute to the availability of vegetable crop in the urban and peri-urban areas of Côte d'Ivoire through the increased productivity of African indigenous leafy vegetables (AILVs). Surveys were conducted to characterise farmers' cultural practices and to identify research needs around Abidjan and Yamoussoukro, the biggest cities of the country. At the research station, trials were conducted to determine good agricultural practices (GAPs) for the four main cultivated AILVs species (amaranth, jute mallow, African nightshade, Lagos spinach). Here, we present results related to amaranth (*Amaranthus* spp.) which is locally referred to as "brom-brou". The paper discusses the following issues in relation to GAPs in amaranth: cultivar selection, planting material, nursery management, germplasm and diversity, breeding, soil fertility and plant nutrition, cropping systems/organic manure, irrigation and water management, post-harvest management, marketing systems and linking farmers to markets.

## CULTIVAR SELECTION, PLANTING MATERIAL AND NURSERY MANAGEMENT

### Cultivar selection

In the urban and peri-urban areas of cities in Côte d'Ivoire, many cultivars of amaranth (or brom-brou) are available. Farmers select their own cultivars which are highly demanded by local markets. At the research level, collected cultivars are being characterised for potential utilization in a selection program (N'zi, 2008). Based on characters such as leaf colour, plant height, and leaf width, four morphological types were identified in the collection of CNRA. On the basis of lateness to flower, three accessions of amaranth (ABAN17, TATRO and YKG05) had been identified for selection. The unavailability of improved amaranth varieties for farmers would be due the absence of previous research on indigenous leafy vegetables in Côte d'Ivoire. Surveys at the Ministry of Agriculture revealed little documentation and a lack of priority granted to these crops in most development agricultural programs of the country (Fondio et al., 2007). Grubben (2004) also noted that selection of amaranth varieties is limited in some west African countries (Benin, Nigeria) to choosing varieties among local cultivars. It is therefore important to establish a breeding program in order to develop improved varieties for farmers.

### Planting material and nursery management

Farmers use saved amaranth seed from previous seasons, which are sown in nursery beds. The preparation of these beds varies from one farmer to another. There are farmers who spread seeds directly on the beds without any fertilisation and no protection technique. In these conditions, plants survival rate is very low varying from 10 to 20%. The second group of farmers prepares the seed beds with mineral and organic manure. After the sowing, they cover the beds with palm leaves (Figure 34). Generally, organic manure is not well-composted.

**Figure 34: Examples of nursery beds prepared by farmers**

For the good agricultural practices in nursery management, the CNRA advises that farmers till the soil properly before preparing beds and that they employ 20 g/m² of NPK 10-18-18 or 2 kg/m² of organic manure made of poultry droppings. This organic manure must be well-composted for about 2 to 3 months before utilisation. Seeds are sown on the beds in lines and are separated from each other by a distance of about 10 cm. Beds are covered with palm leaves for 15 days after sowing, and must be regularly watered. Seedlings are transplanted 25-30 days after seed sowing at true leaf stage (15 cm of height). However, these results of CNRA are not yet disseminated to farmers who pursue to use their traditional practices. Abukutsa-Onyango (2006) reported also that the lack of quality seed constituted a major constraint to the traditional vegetables development and observed that most farmers save their own seed from season to season, and sell surplus to other growers. Grubben (2004) wrote that amaranth could be produced either by using a nursery or sowing directly. But this last method produces low leaf yield and it favors weed occurrence in the fields. The non-dissemination of improved technologies to farmers is the major critic to agricultural research in Africa. While many results are available at the research level farmers are dammed to apply the old techniques. For Centrès (1996), urban agriculture was developed in African cities without agricultural research support. Therefore, it is urgent for research in Côte d'Ivoire to engage action to disseminate new technologies in order to improve the livelihood of small-scale producers.

## GERMPLASM AND DIVERSITY

At the Anguededou research station of CNRA located about 30 km south-west of Abidjan (5°22' N, 4°8' W and 95 m above sea level) a collection of 18 germplasm accessions was established (Table 11). The analysis of variance revealed that these accessions differ significantly for all the characters studied. Little difference was observed among the accessions for days to germination (mostly less than 3 days). For the qualitative characters, all the accessions are spineless. Sixteen accessions had green stems and two had crimson stems. Concerning the type of inflorescence, 16 accessions possessed panicle-type inflorescence while two had umbel type (Table 12). Three groups can be distinguished according to inflorescence colour: green (12 accessions), crimson (3 accessions) and green-crimson (3 accessions). The differences between accessions confirm the diversity of amaranth species. Grubben (2004) noted that *Amanthus* genus contains about 70 species of which 17 are produced for edible leaves. Schippers (2002) observed that several efforts made to clarify the taxonomy of *Amaranthus* led to further confusions due to the many varieties especially within the cultivated groups species. Research is still needed to unravel the complex taxonomy of *Amaranthus* genus.

**Table 11: Quantative characters of 18 amaranth accessions found at the Anguededou research station**

(Source: N'zi, 2008)

| Accessions | Days to germination (days) | Days to flowering (days) | Plant height (cm) | Stem width (cm) | Leafstalk length (cm) | Limb length (cm) | Limb width (cm) | Leaves number | Panicle length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| ABAN04 | 3 a | 45 efgh | 78,3 d | 2,9 b | 6,9 b | 13,3 b | 5,4 cd | 19 cdef | 38,5 abc |
| ABAN17 | 3 a | 42 ghij | 137 a | 5,9 a | 13,8 a | 18,3 d | 8,8 a | 29 ab | 41,2 abc |
| AKSSI07 | 3 a | 48 bcde | 99 abcd | 3,1 b | 10,2 ab | 14,2 ab | 6,4 bc | 16 ef | 35,9 c |
| AMPT02 | 3 a | 41 hij | 92,8 bcd | 4,4 ab | 9,8 ab | 13,9 ab | 6,5 bc | 22 abdef | 39,3 abc |
| YMIL02 | 3 a | 38 k | 126 abc | 4,5 ab | 12,3 a | 15,8 ab | 7,5 abc | 28 abc | 48 ab |
| APB09 | 3 a | 38 jk | 117,5 abcd | 4,1 ab | 9,8 ab | 14,4 ab | 7,2 abc | 31 a | 39 abc |
| YQB06 | 3 a | 45 defgh | 127,2 abc | 4 ab | 9,3 ab | 15,5 ab | 7,5 abc | 28 abc | 40,8 abc |
| YQB06B | 3 a | 46 cdefg | 101 abcd | 2,9 b | 7 b | 6,1 bc | 6,1 bc | 20 bcdef | 42,8 abc |
| YFON01 | 3 a | 40 ijk | 104 abcd | 4,3 ab | 9,7 ab | 14,7 ab | 6,7 abc | 15 f | 42,8 abc |
| YFON04 | 3 a | 44 fghi | 96,8 abcd | 3,7 b | 9,1 ab | 14,5 ab | 6,4 bc | 18 ef | 39,3 abc |
| YGK05 | 3 a | 46 cdefg | 106,3 abcd | 4 ab | 12,5 a | 16,5 ab | 7 abc | 19 cdef | 44,8 ab |
| YKO07 | 3 a | 49 bc | 134,2 ab | 4,4 ab | 10,3 ab | 15,7 ab | 8,1 ab | 25 abcdef | 44 abc |
| YQB08 | 3 a | 47 cdef | 114,8 abcd | 4,3 ab | 11,2 ab | 14 ab | 6,7 abc | 21 bcdef | 36 bc |
| YQB05 | 3 a | 46 cdefg | 132,5 ab | 4,8 ab | 10,6 ab | 12,9 ab | 6,2 bc | 27 abc | 44,5 abc |
| YQR04 | 3 a | 44 fghi | 93,2 bcd | 3,9 b | 10,4 ab | 15,4 ab | 6,8 abc | 18 def | 37 abc |
| AMPT08 | 3 a | 49 bcd | 105,8 abcd | 4 ab | 9 ab | 16,8 ab | 6,7 abc | 26 abcd | 39,2 abc |
| TATRO | 2,3 b | 52 b | 97,7 abcd | 4,1 ab | 10,2 a | 15,9 ab | 4,1 d | 22 abcdef | 48,7 a |
| KNYA | 2 c | 60 a | 87,5 cd | 4,1 ab | 9,5 ab | 12,9 b | 6,3 bc | 17 def | 43 abc |
| Average | 3 | 45 | 108,4 | 4,1 | 10,1 | 14,9 | 6,7 | 22 | 14,5 |
| C.V. | 6,85 | 4,98 | 19,59 | 24,84 | 23,95 | 16,3 | 16,99 | 21,6 | 41,4 |

* Means with the same letter are not significantly different at 5% (Duncan's Multiple Range Test).

**Table 12: Few qualitative characters of amaranth accessions measured at Anguededou research station**

(Source: N'zi, 2008)

| Accessions | Type of inflorescence | Inflorescence colour | Stem colour | Limb colour | Petiole colour | Nervure colour |
|---|---|---|---|---|---|---|
| TATROK | Panicle | Green | Green | Green | Green | Green |
| AMPT08 | Panicle | Green | Green | Green | Green | Green |
| YQB06 | Panicle | Crimson | Crimson | Crimson | Crimson | Crimson |
| ABAN04 | Panicle | Green | Green | Green | Green | Green |
| YKO07 | Panicle | Green | Green | Green | Green | Green |
| AKSSI07 | Panicle | Green | Green | Green | Green | Green |
| YQB06 B | Panicle | Green | Green | Green | Green | Green |
| YFON01 | Panicle | Green | Green | Green | Green | Green |
| APB09 | Panicle | Greenish | Greenish | Green | Greenish | Green |
| KNYA | Umbel | Greenish | Greenish | Green | Green | Green |
| YQB05 | Umbel | Crimson | Crimson | Green | Green | Green |
| YMIL02 | Panicle | Greenish | Greenish | Green | Green | Green |
| AMPT02 | Panicle | Crimson | Crimson | Crimson | Crimson | Crimson |
| YFON04 | Panicle | Green | Green | Green | Green | Green |
| YQR04 | Panicle | Green | Green | Green | Green | Green |
| YGK05 | Panicle | Green | Green | Green | Green | Green |
| YQB08 | Panicle | Green | Green | Green | Green | Green |
| ABAN17 | Panicle | Green | Green | Green | Green | Green |

## BREEDING OF AMARANTH

To this day, CNRA does not have an amaranth breeding program. After characterisation of accessions a breeding program will be initiated. Development of late flowering varieties and resistance to fungal diseases would figure among the major research priorities of this program. Little research of breeding of amaranth seems to be available. Grubben (2004) cited many collections of genetic resources of amaranth at OGFRC in USA, NBPGR in India and AVRDC in Taiwan. African collections of amaranth exist at AVRDC in Tanzania and at NiHort in Nigeria and in other countries. But evaluation trials are necessary to exploit more the genetic variability among this *Amaranthus* genus.

## SOIL FERTILITY AND PLANT NUTRITION

According to Schippers (2000), amaranth requires large amounts of nitrogen and other nutrients and therefore does well in soils that are rich in organic matter. Trials conducted by CNRA to determine an optimal fertilisation regime revealed that manure rate had a significant effect on the number of branches per plot and leaf yield (Table 13). Zero fertilisation was less productive in terms of branching and leaf yield than the two rates of manure application. There was no difference between the two manure rates when applied in combination with mineral fertilizer (NPK). In economic terms, combining 20 t/ha of organic matter and 200 kg/ha of NPK was less expensive. These results show the importance of fertilizers in amaranth production. But a high level of manure does not favour a high leaf yield. In economic terms, a large amount of manure does not always lead to a profitable yield of amaranth. According to Schippers (2000), an application of 20 to 40 t/ha of organic matter is required for a good development of amaranth.

**Table 13: Number of branches per plot and leaves yield of amaranth according to fertilisation regime**

(Source: Fondio, 2009)

| Doses of manure | Number of branches per plot | Leaf yield (t/ha) |
|---|---|---|
| 30 t/ha OM + 300 kg/ha NPK | 489 ab* | 14,7 a |
| 20 t/ha OM + 200 kg/ha NPK | 544 a | 14,2 a |
| Zero fertilisation | 435 b | 9,7 b |
| Means | 489 | 12,7 |
| P | 0,01 | 0,0003 |
| CV (%) | 12,8 | 16,9 |

* Means with the same letter are not significantly different at 5% (Duncan's Multiple Range Test)
OM: organic manure

## CROPPING SYSTEMS/ORGANIC PRODUCTION

The survey revealed that amaranth is produced all year round in the urban zones of Abidjan and Yamoussoukro. The production systems comprised both monocropping and mixed cropping. But the current practice is the association of amaranths with lettuce and chive (*Allium schoenoprasum*) culture (Figure 35). In this system, the main crop is cultivated in the bed and amaranth is planted around the bed. In the monocropping system, amaranth is grown at high density. For farmers, the mixed cropping system provides diversity of vegetables to the market and generates more income. The most commonly used fertilisers are NPK, urea and organic manure. Farmers currently use various combinations of these three fertilisers. The organic manure is made of chicken droppings and wood sawdust. Farmers spread organic manure on beds without composting (Fondio, 2007). The diversity of cultural practices for amaranth among farmers shows the absence of disseminated production technologies for this crop in the country. Every farmer defines his own cultivation techniques. Numerous authors explained this status of the African indigenous vegetables by the low given priority in most agronomic research and development programs (Brush, 1989; Prescott-Allen and Prescott-Allen, 1990). Despite the relative interest devoted to these crops by the international research in recent years, little production technologies have been disseminated to farmers. There is a high need to intensify agronomic research in order to improve the productivity of the African indigenous vegetables such as amaranth which is widely grown in many African countries. It will also be important to empirically establish the best crop combination and practices to minimize diseases and insect pests, to increase land productivity under different component crops, as well as to improve farmers' income.

**Figure 35: Mixed cropping of amaranth with lettuce**

## IRRIGATION AND WATER MANAGEMENT

Amaranth has a high water requirement for its development. During the rainy season, amaranth is not irrigated by farmers. In contrast, farmers irrigate amaranth frequently during the dry season. CNRA advises farmers to irrigate amaranth during the dry season and to supplement rainfall during the wet season. The recommended irrigation schedule is 20 l/m² of water in the morning and evening for the sandy soil. Generally, African indigenous vegetables are produced under rain-fed and irrigation conditions. Pasquini et al. (2009) reported that in Kisumu (Kenya), 90% of farmers grew African indigenous vegetables primarily under rain-fed conditions and a smaller number of them irrigated during the dry season with buckets. In the urban and peri-urban areas of Cotonou (Benin), farmers predominantly used watering cans to grow their crops (Pasquini et al., 2009). It is therefore necessary to conduct specific studies to determine the water requirements of amaranth at all crop developmental stages for establishing an appropriate water management for these indigenous vegetables.

## POST-HARVEST MANAGEMENT

### Harvesting

The harvesting technique depends on the production system (mono- or mixed cropping). Generally, for the monocropping system, farmers harvest by uprooting the whole plant about 30-40 days after sowing. In the mixed cropping system, they cut stems and leaves weekly about 15 cm from the ground. This technique allows new side shoots to develop. At the research station, amaranth is harvested by frequent cutting (Figure 36). Uprooting the whole plant was less yielding than continuous harvesting with topping but the first method provided the smallest leaf size and the best marketable leaf quality (Oluoch et al., 2009).

**Figure 36: Harvesting amaranth by cutting**

### Processing/recipes

In Côte d'Ivoire, amaranth is consumed in local recipes whose processing depends on ethnic groups. In Table 14, we present two recipes with amaranth from two different ethnic groups of the country. Amaranth is particularly rich in vitamin C (65 mg/100 g of fresh matter), magnesium (26 mg/g of dry matter) and calcium (25 mg/g of dry matter). But its content in oxalic acid (anti-nutritional factor) could vary from 5 to 10 mg/100 mg of dry matter (Agbo, 2009). With an overview of literature it appears that today many factors influence traditional vegetable consumption in urban and peri-urban communities in Africa. Vegetable consumption in traditional African societies has undergone substantial changes since pre-colonial days, mainly through interaction with other cultures (Maundu, 1997). With the urbanization, these interactions and changes increase rapidly and frequently. Thus, Delisle (1990) thinks it is now not possible to refer to an average consumer, but to take into account

several cultural backgrounds, socio-economic status, lifestyles and consequently different consumers' needs and behaviours. However, these interactions unfortunately also conduct to the full abandonment of the traditional foods for the exotic meals. Promoting of indigenous vegetable consumption in African cities could prevent population from many chronic malnutrition diseases because of the richness of these vegetables in vitamins and minerals.

**Table 14: Preparation of recipes with amaranth (brom-brou)**

(Source: Agbo, 2006)

| **Recipes** | |
|---|---|
| **Ethnic groups: Dioula, Sénoufo**<br><br>**Region: North**<br><br>**Number of surveyed households: 3** | **Ethnic group: Baoulé**<br><br>**Region: Centre**<br><br>**Number of surveyed households: 8** |
| RECIPE 1: peanut sauce with brom-brou<br><br>Remove leaves from the stalks;<br>Clean or wash them;<br>Boil leaves in water with potassium;<br>Transform boiled leaves into dough;<br>Add amaranth dough to peanut sauce;<br>Add fish or meat;<br>Add seasoning of your choice;<br>Add salt at your taste;<br>Serve with starchy staple (rice, maize paste, etc.) | RECIPE 2: frying of brom-brou leaves<br><br>Remove leaves from the stalks;<br>Clean or wash them;<br>Peel and finely chop them;<br>Boil leaves in water for 20 min.;<br>Fry ingredients in oil;<br>Add boiled leaves to ingredients in oil;<br>Add seasoning of your choice;<br>Add salt;<br>Serve with starchy staple (rice, stew, maize paste, etc.) |
| Cooking time of amaranth leaves: 20 min. | Cooking time of amaranth leaves with ingredient: 10-15 min. |

## Packaging

Vegetables are highly perishable products. A suitable packaging is necessary to facilitate the conservation of product quality and transportation to the markets. Unfortunately, appropriate packaging is often non-existent in vegetable markets in Côte d'Ivoire. Indeed, producers and traders wrap their products in bags to transport them from the site of production to the market. In these markets, leaves are generally sold in bundles. In the context of good agricultural practices and in order to promote traditional vegetables for poverty alleviation in Africa, it is necessary to develop and ensure widespread adoption of appropriate packaging for these traditional vegetables. This will greatly facilitate transportation to the market, enhance the quality of products on sale in the market, and increase availability of high quality amaranth and farmers' income in Côte d'Ivoire.

## Storage/preservation

Generally, farmers harvest amaranth a day before or the same day of the sale. Leaves harvested the day prior to sales are stocked in open air in a heap that is sprinkled with water to preserve leaf freshness. There is no preservation method used for amaranth leaves in Côte d'Ivoire. Producers and sellers (usually intermediaries who are retailers or wholesalers) struggle to sell all their produce to avoid waste of any surplus that may not be bought. Grubben (2004) noted that leaves of amaranth could be dried in the sun in order to produce powder which is used during the period of shortage. Drying traditional vegetables seems to be common practice in South Africa, Zimbabwe, Burkina Faso, etc. (Vorster et al., 2007; Chigumira and Mvere, 1999; Legay, 2004). However, the question is what effect this technique produces on the vitamins and minerals content in the dried produce. Therefore, it

would be important to develop storage/preservation facilities for amaranth leaves in order to address the problem of shortage or to enable a regulation of the market in periods of abundance in Côte d'Ivoire.

### Marketing systems and linking farmers to the markets

A real path exists for the marketing of traditional vegetables and particularly for leafy vegetables. With respect to market access, producer access the market and sell their produce in two ways. Firstly, by the direct sale of amaranth at the production sites, this is achieved through retailers or wholesalers. The second means consists of farmers going directly to the market to sell their produce. In the majority of cases, the producer is linked to the markets by intermediaries who are retailers or wholesalers (Mahyao, 2007). Weinberger and Pichop (2009) also identified many actors along the supply chain of indigenous vegetables in urban and peri-urban areas of sub-Saharan Africa (Côte d'Ivoire, Benin, Tanzania, Uganda, etc.). These actors comprised: producers, intermediaries, retailers and wholesalers. But the effectiveness of this supply chain is limited by the informal character of the marketing system (difficulty to access information, lack of credit, low educational level of actors, etc.). To perform the marketing system, there is an increased need for policy-makers at municipal and national level to address the major constraints so that indigenous vegetables can continue to play a significant role in providing jobs, food security and income for the resource poor (Weinberger and Pichop, 2009).

## CONCLUSION

This review of good agricultural practices in amaranth has allowed us to assess current practices in the production of this African leafy vegetable in Côte d'Ivoire and to assess future actions necessary for the effective application of GAP in amaranth in sub-Saharan Africa. We consider that the following research actions must be initiated in Côte d'Ivoire for the promotion of traditional leafy vegetables such as amaranth through the application of good agricultural practices. There is the need to:

1. Empirically establish the best crop combination and crop management practices in different cropping systems in order to increase land productivity under different component crops, as well as to improve farmers' income;
2. Define the optimal irrigation regime for amaranth on the basis of water requirements at different crop developmental stages;
3. Promote recipes of amaranth in order to contribute to increased consumption of this leafy vegetable among the population;
4. Improve the packaging of amaranth to conserve the quality of the produce, and for easy transportation and sale in the market;
5. Perform the marketing system in order to allow the indigenous vegetables such as amaranth to play an important role in providing jobs, food and nutritional security and income for small-scale actors of the chain.

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# Good Agricultural Practices for Production of Ethiopian Mustard (*Brassica carinata* A. Braun) in Sub-Saharan Africa

**Adefris Teklewold[1], Bulcha Woyessa[1], Misteru Tesfaye[1], Adugna Wakjira[1], Silivester N. Samali[2] and Chris O. Ojiewo[3]**

[1]*Holetta Research Center, Ethiopian Institute of Agricultural Research, P.O. Box 2003, Addis, Ethiopia*
[2]*Horticulture Research and Training Institute (HORTI), Tangeru P.O. Box 1253, Ababa, Ethiopia*
[3]*ICRISAT-Malawi, Chitedze Agricultural Research Station, Box 1096, Lilongwe, Malawi*

**Abstract**

Ethiopian mustard, locally known as "gomenzer" is among the oldest oil crops widely cultivated in Ethiopia but grown on limited scale in other parts of Africa as a leafy vegetable. It is an amphidiploid with one genome from *Brassica nigra* and the other from *Brassica oleracea*. The crop is believed to have evolved in the highlands of Ethiopia and adjoining portions of east Africa and the Mediterranean coast. Cultivation of Ethiopia mustard as leaf vegetable is limited to small-scale production but it is slowly gaining popularity in rural as well as urban areas where commercial production is taking place. The crop is best grown in the mid to high altitude (2000 to 2600 m) areas on more fertile, well-drained soil often close to homesteads that are rich with organic matters. Optimum cultural practices such as appropriate sowing date (early to late June) and 12-15 kg/ha seed rate have been recommended. Fertilizer rate of 46/69 kg/ha of $N/P_2O_5$, respectively, and two hand-weeding at 25-30 and 50-60 days after sowing were found good practices for superior vegetative growth and hence high seed yield. Extent and intensity of defoliation experiments have shown no significance and consistent effects on seed yield and oil contents due mainly to compensatory effects. Better varieties, agronomic practices and crop protection measures are still required in terms of improved yields and qualities of leaves, seeds, oils and meals.

**Keywords:** ethiopiam mustard, *Brassica carinata*, agronomy, seed oil, leafy vegetable

## INTRODUCTION

African indigenous vegetables (AIVs) play an important role in food security of the underprivileged in both urban and rural settings (Schippers, 1997). Ethiopian mustard (*Brassica carinata* A. Braun) is one of the AIVs grown and consumed in most parts of Africa mainly as leafy vegetable but in Ethiopia, it is among the oldest oil crops (Simmonds, 1979). In Tanzania, Ethiopian mustard is among the priority AIVs (Weinberger and Msuya, 2004).

It is an amphidiploid with one genome from *Brassica nigra* (L.) Koch and the other from *Brassica oleracea* L. (Oyen and Umali, 2007). The crop is believed to have evolved in the highlands of Ethiopia and adjoining portions of east Africa and the Mediterranean coast (Simmonds, 1979). It is the third most important oil crop in the highlands of Ethiopia (Teklewold, 2005). Owing to its drought and heat tolerance, the crop is now being considered as an alternative to *B. napus* and *B. juncea* in dryer areas of Canada and as a potential oil crop in Spain and India (Teklewold, 2005).

## USES OF ETHIOPIAN MUSTARD

The cultivation of *Brassica carinata* as an oil crop is largely limited to Ethiopia, but as a leafy vegetable it is often grown in most countries of sub-Saharan Africa (Mnzava and Schippers, 2007). Farmers often harvest its top parts by cutting off the upper tender parts (growing tips including 2-3 leaves) at 30-50 cm height to sell in local markets or for home consumption as green vegetables. Consumers boil these lushly vegetables, and mix them with different food items like meat, potato, butter, oil and spices. The leaves are largely consumed during summer season, when shortages of most crops encounter usually after the planting season (July-September). The tender leaves and sprouts are also boiled and eaten especially during periods of fasting, commonly among the Coptic.

In practice, so many rural dwellers depend on such vegetable foods especially during food scarcity seasons to rescue their lives. Because of such traditional consumption patterns, it is often regarded as poor people's food. Such leafy vegetables are mostly grown as a garden crop in Ethiopia, although in Tanzania, Malawi, Zambia and Zimbabwe it is also grown as a market crop (Mnzava and Schippers, 2007). Mustard seeds are used to produce oil that can be used for both edible and industrial purposes. Its oil is used for different services, such as edible oil, greasing, traditional bread-making, tanning leather, curing certain ailments, and production of water repellents, waxes, polyesters and lubricants. Seed cake remaining after extraction of oil can be used as fertilizer or animal feed. It is also used as a green fodder crop, green manure and as a cover crop (Alemayehu, 2001). The oil is often adulterated with oils from Niger seed or linseed in Ethiopia to ameliorate its taste and flavor. People in Ethiopia use the sharp-tasting seeds as a spice to flavor raw meats. In the recent past, there has been increasing interest in utilizing the oil, like other *Brassica* seed oils, as a biodiesel and for the preparation of special erucic acid derivatives.

## NUTRIENT COMPOSITION

Nutritional composition of *Brassica carinata* leaves was reported to be comparable to *Brassica juncea* (Mnzava and Schippers, 2007). Ethiopian mustard nutritional composition has recently been analysed by AVRDC nutrition laboratory (Table 15). Seeds of mustard are rich in oil, containing 25-47% depending on cultivar and growing conditions; the protein content is also high, 25-45% and comparable to that of pulses. The oil consists of: erucic acid 35-44%, linoleic acid 15-22%, linolenic acid 16-20%, oleic acid 10-12%, eicosenoic acid 7-9% and palmitic acid 2-4%. Lines containing oil without erucic acid have been developed through cross-breeding with *Brassica juncea* and *B. napus* L. and through mutagenesis. The seeds have a high content of glucosinolates (100-200 µmoles/g), almost exclusively sinigrin, which has both antioxidant and goitrogenic properties. Ethiopian kale is reported to have less glucosinolate than rape, *B. juncea*, which is one good reason for eating *B. carinata* rather than rape (Mnzava, 1997). *B. carinata* produces the phytoalexin brassilexin and several of its precursors in response to attack by the blackleg pathogen *Leptosphaeria maculans*, which may explain its resistance to the disease (Mnzava and Schippers, 2007).

**Table 15: Nutritional facts for young leaves of Ethiopian mustard per 100 g fresh weight**

(Source: AVRDC, 2010)

| | |
|---|---|
| Dry matter (g) | 11.3 |
| Protein (g) | 3.37 |
| Fiber (g) | 1.48 |
| b-carotene (mg) | 0.29 |
| Vitamin C (mg) | 183 |
| Vitamin E (mg) | 1.80 |
| Calcium (mg) | 153 |
| Iron (mg) | 1.39 |
| Zinc (mg) | 0.72 |
| Antioxidant activity (µmol trolox) | 849 |
| Total phenols (mg) | 260 |
| Oxalates (mg) | 13 |

## GENETIC DIVERSITY AND GERMPLASM RESOURCES

In Africa some breeding work has been done and several selections have been made in Tanzania, Zambia and Zimbabwe. Selection criteria are leaf size, late bolting, reduced susceptibility to major diseases and pests, and high yield. Well-known cultivars are ‘White Figiri’, ‘Purple Figiri’, ‘Lushoo’, ‘Mbeya Green’ and the large-leaved ‘Lambo’ from Tanzania, ‘RRS-V’ from Zimbabwe, ‘Chibanga’ and ‘NIRS-2’ from Zambia. In Zambia, Ethiopian kale has been crossed with Portuguese cabbage and with *Brassica nigra*. More breeding work has taken place on cultivars used for oilseed, mainly in Canada, India and Italy. Low erucic acid and glucosinolate content and high seed yield are major selection criteria.

The genetic diversity in *B. carinata* based on molecular DNA markers is much less than in *B. juncea*. In spite of the comparatively small variation in *B. carinata*, there are many landraces for both the oilseed and the leafy vegetable types, differing in earliness, plant structure, leaf size, shape and structure, seed yield, and glucosinolate and erucic acid levels in the seed. There is a need for further collection, conservation and evaluation of this diversity before farmers start using new cultivars at the expense of their traditional landraces. A collection is maintained at the Centre for Genetic Resources (CGN), Wageningen, the Netherlands. Working collections are available at research institutions in Ethiopia, Tanzania, Zambia and Zimbabwe. High genetic diversity of Ethiopian mustard is expected in countries such as Tanzania due to the presence of 9 different agro-ecological zones which represent one of the 26 hotspots of biodiversity in the world (Anonymous, 2004).

Genetic divergence of 36 germplasm collections from diverse ecological regions of the mid- and high altitude areas of Ethiopia were studied based on multivariate analysis of morphological data from multi-location trials. The results have generally revealed that there was an enormous amount of genetic variability among the *B. carinata* accessions collected from Ethiopia. There were highly significant differences in all the traits among the accessions, the testing sites and their interaction (Table 16). The largest part of the total variance accounted for the differences due to locations followed by those accessions and the interaction between the genotypes and locations (Alemayehu, 2001).

**Table 16: Mean squares from the analysis of variance for some morphological traits of Ethiopian mustard accessions**

| Source | Degree of freedom | Plant height (cm) | No of primary branch per plant | No of secondary branch per plant | Days to the beginning of flowering | Days of flowering | Days to maturity |
|---|---|---|---|---|---|---|---|
| Location | 2 | 694* | 102** | 1990** | 1846** | 1673** | 6801** |
| Replication/Location | 3 | 0.66 | 1 | 5 | 20* | 12 | 12 |
| Accession | 35 | 21** | 4** | 68** | 392** | 911** | 624** |
| Location/Accession | 70 | 2** | 2** | 52** | 15** | 17** | 67** |
| Error | 105 | 0.28 | 0.71 | 4 | 5 | 5 | 5 |

## CROP IMPROVEMENT

The principal aim of the genetics and breeding research on Ethiopian mustard is generally to increase productivity and quality of Ethiopian mustard in terms of seed yield where oil production is intended and leaf yield where it is intended to be used as a leafy vegetable. Over the past three decades, the Ethiopian mustard-breeding program has made substantial breeding activities such as, enhancement of germplasms, selections, crossing and different variety or yield trials (Nigussie et al., 2003). Leaf harvesting did not show significant seed yield reductions and might increase the total yields (Figure 37). It is, therefore, realized that Ethiopian mustard has an effective dual benefit for farmers as vegetable and seed source for oil and other traditional uses.

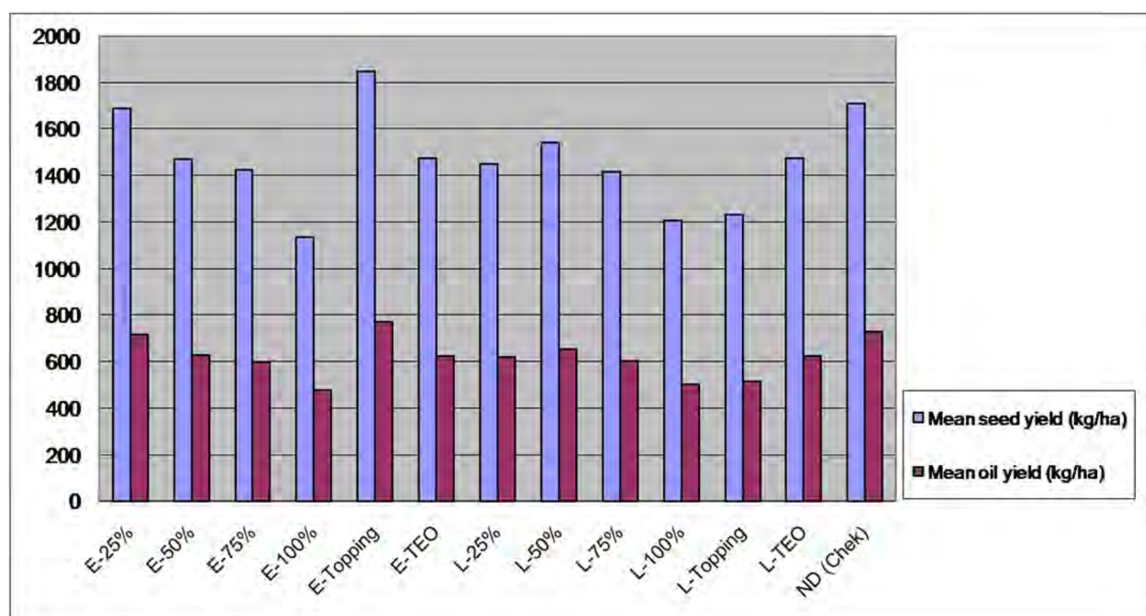


**Figure 37: Mean effect of stage and intensity of defoliation on seed and oil yields of Ethiopian mustard at 5 locations in Ethiopia, 1998**

* E = Early at 30 cm height, L = Late at 50 cm; TEO = topping every other plant; ND = no defoliation or check plots

## AGRONOMIC AND CROP MANAGEMENT PRACTICES

### Nursery and land preparation

Ethiopian mustard is a small seeded crop and requires a leveled fine seedbed for optimum germination. Propagation method for Ethiopia mustard is normally by seed. The weight of 1000 seeds is 3-5 g. When grown for the leaves, sowing in a nursery and transplanting are widely practiced. Seedbeds are normally raised above the soil to reduce the incidence of damping off. The top layer is dug and some well-decomposed manure is worked in to produce a friable soil. Seeds are drilled in the nursery in lines 15-20 cm apart. Watering in the nursery should be done with a fine rose. Farmers may cover the seedbeds with long grass or similar material to keep the surface moist and dark. When the cotyledons have spread after germination, this mulch is removed or placed next to the plantlets. Seedlings can be transplanted at the 4-leaf stage when seedlings are about 7-8 cm high, about 5 weeks after germination. When seedlings become too tall, they may become spindly and unlikely to develop into strong plants.

For its large-scale production, a single primary plowing with a moldboard plow and twice harrowing with a disc harrow is sufficient for a field, which previously was under crop. The primary tillage and the first harrowing shall be done during the period of the short rains (March-April in Ethiopia) and the second harrowing a week or two before the time of seeding. If the plowing operation has to be done with animal-drawn implement, the “maresha”, three plowing are in order. The first two tillage operations are to be done during the short rain and the third just before planting in June (Nigussie et al., 2003). In irrigated areas, the first plowing is done with a medium sized soil-turning plough, followed by two to four plowing with a disc plough or a cultivator.

### Sowing

Ethiopian mustard is very sensitive to sowing dates but is much less sensitive to a wide range of seed rates and also to sowing methods (Nigussie et al., 2003). For most of the growing areas in Ethiopia, Ethiopian mustard is planted one or two weeks after the onset of steady rains. The time from sowing to emergence of the seedling is about 5-6 days, depending on temperature and soil moisture. A wide range of seed rates 5-25 kg $ha^{-1}$ are usually used depending on method of sowing. For standard practices, 12 kg $ha^{-1}$ is found optimum for row sowing, while 15 kg $ha^{-1}$ is apt for broadcasting. When planting is done in rows, the seeds can either be drilled or placed in hills of regular intervals. With the latter case, 2-3 seeds have to be placed in each hill in order to ensure the development of at least a single viable seedling. In case all the seeds in a hill germinate, the excess seedlings have to be thinned out later while weeding. After sowing is done, the seeds will then have to be covered with a thin layer of soil (2-3 cm depth) so that they will not be picked up by birds or washed away by the rain.

### Spacing

Plant spacing varies depending on the cultivar/variety and level of soil fertility among other factors. Field spacing of about 50-60 x 35-40 cm depending on the plant size is common. However, for varieties with larger leaves such as the ones found in west Africa and Tanzania, spacing of about 75 x 50 cm and 50 x 30 cm for the small leaved varieties found in Zambia and Zimbabwe have been reported (Schippers, 1997). According to AVRDC (1993), experimental results from Tanzania indicated optimum spacing for Ethiopian mustard to appear to be 60 x 45 cm or 60 x 30 cm.

Trials conducted in Arusha, Tanzania in 2007 investigated more on the effect of closer spacing on leaf yield of selected Ethiopian mustard lines and results indicated that generally the highest yields were obtained from closer spacing (30 x 30 cm, 30 x 40 cm, 40 x 30 cm,

and 50 x 30 cm) (Table 17). Wider spacing on the other hand gave the lowest leaf yield. On the other hand, Ethiopian mustard growers seem to have adopted high density sowing for once-over harvesting of this crop.

**Table 17: Effect of spacing on leaf yield of Ethiopian mustard**

| Spacing (cm) | Yield (t/ha) | | | |
|---|---|---|---|---|
| | Mbeya green | Research station | Field station | Ihanja |
| 30 x 30 | 35.7a* | 33.3a | 22.4ab | 18.6ab |
| 30 x 40 | 33.4a | 24.9bc | 15.4bc | 13.6bc |
| 30 x 50 | 22.6bcde | 18.3cd | 15.9abc | 12.7bc |
| 40 x 30 | 22.2bcde | 28.9ab | 24.4a | 20.7a |
| 40 x 40 | 19.9bcde | 19.9cd | 16.9abc | 12.6bc |
| 40 x 50 | 14.9def | 16.4de | 15.2bc | 8.8cd |
| 50 x 30 | 23.3bc | 19.9cd | 19.5ab | 12.1c |
| 50 x 40 | 15.9cdef | 16.2de | 14.7bc | 11.5cd |
| 50 x 50 | 15.3def | 12.6de | 14.0bc | 7.7cd |
| 60 x 30 | 16.0cdef | 13.2de | 15.9abc | 8.9cd |
| 60 x 40 | 14.1ef | 8.4e | 9.8c | 8.6cd |
| 60 x 50 | 10.9f | 8.9e | 10.0c | 5.3d |
| LSD0.05 | 6.89 | 7.18 | 7.59 | 5.79 |
| CV (%) | 19.77 | 23.06 | 27.69 | 29.12 |

* Means within the same column followed by same letter(s) are not significantly different at 5% probability level according to Duncan's Multiple Range Test (DMRT)

## Fertilizer

Generally, the *Cruciferae* family is a heavy feeder of soil nutrients. Ethiopian mustard being in the family of *Cruciferae* requires fertile soils with high organic matter. Ethiopian kale responds well to farm yard manure (FYM) but this is not always available. Instead, farmers may opt to apply inorganic fertilizers. In the case of FYM availability and depending on the level of soil fertility, as much as 50-60 t/ha is incorporated into the soil at land preparation stage. However, higher rates of FYM to the level of 150 t/ha have been reported in Tanzania (AVRDC, 1993).

Most farmers find it easier to apply chemical fertilizers such as NPK or DAP in the planting holes or evenly broadcasted in the prepared field (basal application). Rates of about 100 kg N/ha and 75-100 kg P/ha are common practices. However, it is important to do soil analysis before fertilizers are applied. It is also important to top-dress with nitrogenous fertilizers such as urea or sulphate of ammonia (SA) 50 kg N/ha once per fortnight from the moment that leaf harvesting begins. Higher levels of nitrogen will increase proteins and enhance leaf production, whereas more phosphorous will enhance seed production potential. Some vegetable farmers will therefore increase the initial amount to 300 kg N, whereas others give a fortnightly side dressing of 50 kg N at a time.

Fertilizer rate of 46/69 kg/ha of $N/P_2O_5$, respectively were found optimum in Ethiopia (Nigussie et al., 2003).

### Weeding

Two hand weeding at 25-30 and 50-60 days after sowing and a seed rate of 12 kg/ha were found with the best return of seed yield. Higher yields have generally been obtained when sowing was done not later than three weeks after the commencement of the main rains. Thus, optimum sowing date ranges from late May for the high altitude and cool areas of south-eastern zone early to late June for the central highlands of Ethiopia. Studies on the effects of various technology packages on seed yield of Ethiopian mustard have demonstrated that an increase in seed yield ranging from 20 to 29% can be obtained by adoption of full technology package as indicated in figure 38 (Nigussie and Mesfin, 1994).

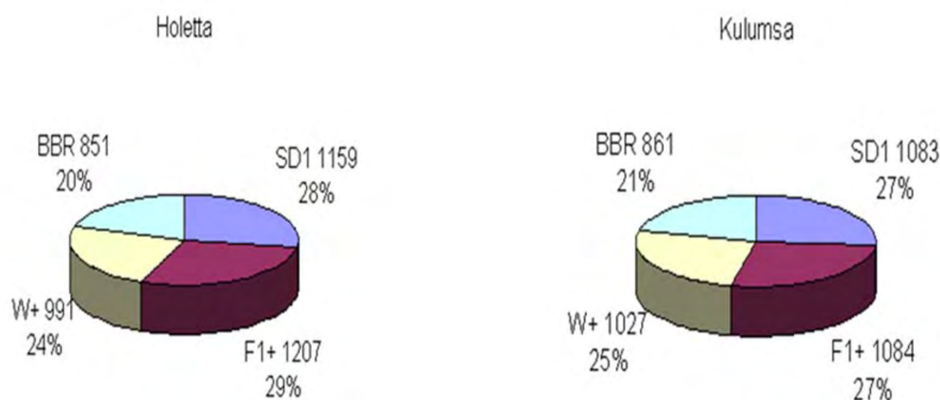


**Figure 38: Relative contribution (%) of mean effects (kg ha$^{-1}$) of early sowing (SD1), fertilizer (F+), weeding (W+), and broadcasting (BBR) on seed yield of *Brassica carinata* at Holetta and Klumsa (1988-1989)**

### Drainage

Adequate moisture is necessary for high quality leaf yield of Ethiopian mustard. It is therefore, important to irrigate Ethiopian mustard frequently depending on the level of moisture in the soil. Adequate moisture in the soil will also enhance mineral uptake from the soil. Moisture stress on the other hand induces early flowering in Ethiopian mustard.

Newly sown seeds are covered only very thinly and thus can easily be washed away by flooding if it occurs soon after planting. Equally sensitive to either flooding or standing water are both the seedling and adult plants of mustard (Nigussie et al., 2003). It is therefore crucial to construct and maintain ditches and waterways to check the flooding. Drainage ditches are better if constructed along fields.

### Harvesting

As it has been stated earlier, Ethiopian mustard has dual utility (as vegetable and seed source for oil or other traditional purposes) and thus harvesting time and methods vary with type of plant part used. If the plant is used as source of vegetable, mustard leaf is usually harvested when the plants reached 30 cm tall (early harvesting) and 50 cm (late harvesting). New leaves will provide a continuous harvest until they are lignified and become too tough to cook. Plants from seeds that were broadcasted at high density can be harvested by uprooting the whole plant 5-6 weeks after sowing. This method is normally used when the land is needed for another crop. For a conventional crop, the first harvest takes place about 5 weeks after

transplanting. Leaf harvesting is best done once in 2 weeks with 50% defoliation. Small-leaved cultivars are often collected in the form of shoots rather than as individual leaves.

When the plants are targeted for seeds, harvestings are done when seeds are fully ripe before they start shattering (Nigussie et al., 2003). Inflorescences are cut and placed on a tarpaulin or similar sheet, where they are allowed to dry without risk of seed shattering. The crop is then threshed and winnowed. After drying the pods for one to three weeks depending on weather conditions, the harvested plants are threshed by using oxen or horses. Farmers also beat with a stick if they have small quantity and if animals are not available. The liberated seed is sieved and winnowed to achieve pure seeds.

**Leaf and seed yields**

Leaf yields vary considerably between cultivars/varieties but yields ranging between 30-35 t/ha from research reports are common. Trials conducted at HORTI Tengeru, Arusha, Tanzania under irrigation involving 17 accesions of Ethiopian mustard between July and November 2007 indicated total leaf yield ranging between 12-40 t/ha and a seed yield ranging from 13-44 t/ha (Table 18). When the same trial were repeated between April to August 2008 at the same site using the same accessions, total leaf yield ranged between 17-47 t/ha, and the seed yield ranged between 20-44 t/ha (Table 19). Yields ranging between 50-55 t/ha have been reported from other research stations in various parts of Africa. Yields vary depending on cultivars, production season or under irrigation, and levels of management practices. Recently, line ML EM 1 developed by AVRDC has proved to be of high potential and is earmarked for release in Tanzania. Multilocational trials and DUS tests are on-going in various parts of Tanzania, conducted by AVRDC-The World Vegetable Center, HORTI-Tengeru and Tanzania Official Seed Certification Institute (TOSCI) to facilitate its official release.

**Post-harvest management**

While using Ethiopian mustard as vegetables the quality of the harvested leaf is assessed based on the appearance, texture and flavor. Most of the time vegetables are consumed in fresh status without storage. The other option is keeping for few days in moist containers, for 1 or 2 days. If seed is important it should be kept stored in bags, sacks, clay pots or cans in dry, clean, cool and aerated stores. The seeds of Ethiopian mustard can maintain its viability for 15 years if it is stored under well-aerated and dry conditions. The leaves are rather perishable and wilt or become yellow when left on the shelf for more than a day. Farmers therefore harvest small quantities at a time. To retain freshness, the leaves are kept moist inside a bag that is left in the shade or in a cool place. When the product is offered as whole plants with roots, traders place the roots in water and plants can thus be kept for a few days.

**Table 18: Yield and horticultural characteristics of Ethiopian mustard lines during July to November 2007 at HORTI Tengeru**

| Line/Accession | Non marketable yield (t/ha) | Marketable fresh leaf yield (t/ha) | Total leaf yield (t/ha) | No of pods/plant | No of seeds/pod | Seed yield (t/ha) | 200 seed weight (g) |
|---|---|---|---|---|---|---|---|
| 1. Rw-B-1 | 0.35e | 13.32f | 15.38e | 1059.67cd | 11.9bcd | 29.77d | 8.77ab |
| 2. ML-EM-1 | 1.72ab | 30.3abc | 39.9a | 1139.67cd | 10.15d | 29.07d | 8.93ab |
| 3. ML-EM-3 | 0.73cde | 24.3cde | 28.46abcd | 1664.67b | 10.8bcd | 44.93b | 8.17ab |
| 4. ML-EM-7 | 0.97cd | 32.9ab | 39.58a | 1119.33cd | 11.28bcd | 31.03d | 8.37ab |
| 5. ML-EM-8 | 0.44de | 21.77de | 24.62cde | 1183.67c | 11.62bcd | 34.33d | 8.97a |
| 6. TzSMN 36-5 | 0.44de | 23.6cde | 26.16bcde | 1648.67b | 10.47d | 43.13bc | 8.6ab |
| 7. TzSMN 44-6 | 0.97cd | 34.13a | 40.2a | 760.33e | 10.55cd | 19.87e | 8.8ab |
| 8. TzSMN 52-9 | 1.26bc | 25.37bcd | 32.7abc | 1136.33cd | 12.33bcd | 35.13cd | 8.33ab |
| 9. ST 25B | 1.02cd | 20.8de | 27.03bcd | 1080.67cd | 13.13ab | 35.33cd | 8.93ab |
| 10. ST 2 | 1.6ab | 27.8abcd | 37.26ab | 1182c | 10.42d | 30.67d | 8.3ab |
| 11. ST 4 | 0.96cd | 17ef | 12.39e | 1078.33cd | 11.73bcd | 31.5d | 8.8ab |
| 12. ST 57 | 1.71ab | 26.04bcd | 34.13abc | 950d | 11.93bcd | 29.77d | 9.1a |
| 13. ST 18 | 1.71ab | 25.50bcd | 34.9abc | 1231.33c | 10.48d | 32.23d | 8.67ab |
| 14. ST 3 | 0.53de | 17.29ef | 21.07de | 2458.33a | 11.17bcd | 68.5a | 8.0ab |
| 15. ST 68A | 2.05a | 22.00de | 34.04abc | 1047.33cd | 14.62a | 33.63d | 8.23ab |
| 16. ST 15 | 0.97cd | 21.69de | 27.27bcd | 1097.67cd | 12.95abc | 35.4cd | 8.73ab |
| 17. MG | 1.6ab | 28.33abcd | 36.97ab | 1099cd | 11.23bcd | 30.87d | 7.7b |
| CV (%) | 28.52 | 16.47 | 20.13 | 8.67 | 10.60 | 13.41 | 7.32 |

*Means within the same column followed by same letter(s) are not significantly different at 5% probability level according to Duncan's Multiple Range Test (DMRT)

**Table 19: Yield and other horticultural characteristics of Ethiopian mustard lines during April to August 2008 at HORTI Tengeru**

| Line/Accession | Marketable fresh leaf yield (t/ha) | Non marketable fresh leaf yield (t/ha) | Total leaf yield (t/ha) | No of pods/plant | No of seeds/pod | Seed yield (t/ha) | 200 seed weight (g) |
|---|---|---|---|---|---|---|---|
| 1. Rw-B-1 | 13.29h | 4.1bcde | 17.39g | 1026.33cde | 4.07g | 28.34de | 8.4ab |
| 2. ML-EM-1 | 23.67cdefg | 6.91abc | 30.58bcde | 998cde | 14.35cdef | 28.67de | 8.83a |
| 3. ML-EM-3 | 20.31defgh | 3.97bcde | 24.28defg | 1733.67b | 20.8bcd | 42.41ab | 8.03ab |
| 4. ML-EM-7 | 23.77cdefg | 4.83abcde | 28.59cdef | 950e | 23.02abc | 31.56bcde | 8.13ab |
| 5. ML-EM-8 | 15.76fgh | 2.17e | 17.93g | 1130.33c | 5.53efg | 34.0bcd | 9a |
| 6. TzSMN 36-5 | 28.88bcd | 2.78de | 31.66bcd | 1637.67b | 27.64ab | 42.45abc | 8.43ab |
| 7. TzSMN 44-6 | 43.47a | 5.41abcde | 46.88a | 616.33f | 4.85fg | 20.31e | 8.77ab |
| 8. TzSMN 52-9 | 15.56gh | 4.37abcde | 19.92fg | 1088cde | 27.24ab | 34.22bcd | 8.47ab |
| 9. ST 25B | 27.88bcd | 5.93abcd | 33.8bc | 1063cde | 20.92bcd | 34.32bcd | 8.67ab |
| 10. ST 2 | 31.95bc | 7.69a | 39.64b | 1072cde | 12.72defg | 28.89de | 8.47ab |
| 11. ST 4 | 25.97bcde | 1.09abcd | 32.07bcd | 1060.67cde | 18.78bcd | 30.04cde | 8.83a |
| 12. ST 57 | 21.18defgh | 7.7a | 28.88cdef | 657.33de | 8.21efg | 29.31de | 9.07a |
| 13. ST 18 | 22.82defg | 5.84abcd | 28.66cdef | 1115.67cd | 14.81cde | 32.5bcde | 8.73ab |
| 14. ST 3 | 23.99cdefg | 6.88abc | 30.86bcde | 2437.67a | 28.04ab | 48.64a | 8.07ab |
| 15. ST 6 | 18.13efgh | 3.45cde | 21.58efg | 1115.33cd | 18.64bcd | 32.77bcde | 8.27ab |
| 16. ST 15 | 32.44b | 7.03ab | 39.46b | 1057.33cde | 31.64a | 34.49bcd | 8.6ab |
| 17. MG | 24.27bcdef | 6.44abc | 30.71bcde | 1009.67cde | 24.18abc | 30.58cde | 7.67b |
| CV (%) | 18.28 | 32.79 | 16.38 | 7.09 | 29.47 | 19.35 | 6.79 |

*Means within the same column followed by same letter(s) are not significantly different at 5% probability level according to Duncan's Multiple Range Test (DMRT)

## CONCLUSIONS

The Ethiopian mustard is among the oldest oil crops cultivated in Ethiopia since antiquity both as an oilseed and vegetable crop. It is has been in service as the main dish and cash crop for small-scale farmers especially at the time of food and income shortages. Subsistence farmers grow it near their homestead and defoliate the vegetative shoots twice or trice per growing seasons for leafy vegetable, and the remaining plant is harvested when seeds are matured as oilseeds. The crop is also resistant to black-leg (fungal disease) as compared to its relatives *Brassica napus*. The development of high yielding and superior quality for oil and meal values will continue as the main research agenda for its further improvement in Ethiopia. Better varieties are also required in terms of improved seed and oil yields besides leafy types for vegetable usages.

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# Guidelines on Good Agricultural Practices in the Production of Moringa (*Moringa oleifera* Lam)

**V.E. Emongor**

*University of Botswana, Botswana College of Agriculture, Faculty of Agriculture, Crop Science and Production Department, Private Bag 0027, Gaborone, Botswana (v_emongor@yahoo.com or vemongor@bca.bw, Phone: 267-3650141, Fax: 267-3928753)*

**Abstract**

The moringa tree, *Moringa oleifera*, is among the most underutilized multipurpose tropical crops. All the parts of the moringa tree are edible and have for long been consumed by humans. Moringa can be used for alley cropping (biomass production), animal feed (leaves and treated seed cake), biogas (leaves), water purification (powdered seed), dye extraction (wood), medicine (all plant parts), vegetable (leaves), oil extraction (seed), plant growth enhancer (juice extracted from leaves), fertilizer (seed cake), manure (leaves), honey and sugar cane juice clarifier (powdered seed), gum (tree trunks), biopesticide (soil incorporation of leaves to prevent seedling damping off), tannin for tanning hides (bark and gum), biofuel (oil from seed) and ornamental planting. The moringa leaves and pods are an outstanding natural source of digestible protein, minerals (calcium, iron, magnesium, potassium, phosphorus, sulphur, manganese and zinc), vitamins (vitamin A-β-carotene, vitamin B-choline, vitamin $B_1$-thiamine, vitamin $B_2$-riboflavin, vitamin $B_3$-nicotinic acid, vitamin C-ascorbic acid and vitamin E-tocopheral acetate) and essential amino acids (arginine, histidine, tryptopha, phenylalanine, leucine, methionine, threonine, isoleucine, valine, glutamic acid, glycin, etc.). Moringa leaf powder can be used as a supplement to boost or stimulate the immune system of HIV positive people. Taking moringa leaf powder three times a day (15 g) has been shown to increase the CD4 cells and lower the virus load in HIV positive patients. Global industrialization and the increasing demand for environmentally friendly products makes moringa have great potential as a source of pharmaceuticals, dyes, biofuel, human food, animal and fish feed, and water purification products. The moringa products consumed are wholesome and free of microorganisms that could result in illness under common and sensible handling and food preparation practices. In addition, moringa leaves, pods, seeds, bark, roots and leaf powder have natural barriers and phytochemicals that minimize the chance that any surface contamination could be transferred to the internal edible portions, up to the point of harvest. These same barriers increase the effectiveness of removal of contamination during washing, processing and packaging.

**Keywords:** underutilized tropical crop, nutritional supplement, immune booster, HIV/AIDS, biofuel, good agricultural practices

## INTRODUCTION

*Moringa oleifera* (synonym: *Moringa pterygosperma* Gaertner) belongs to the family *Moringaceae* which is a single genus family of shrubs and trees cultivated across the whole of the tropical belt and used for a variety of purposes (Jahn, 1986). The genus *Moringa* comprises of 13 species, of which 8 are endemic to the Horn of Africa. *M. oleifera* is most closely related to *M. concanensis* Nimmo (from India) and *M. peregrina* (Forssk.) Fiori (from the region around the red Sea, the Horn of Africa, Yemen and Oman). These 3 species share a slender tree habit and the zygomorphic flowers. Moringa (*M. oleifera*) is a slender, graceful, fast growing, aesthetically pleasing, deciduous to semi-evergreen, perennial shrub or small

tree reaching 9-15 m in height, with an umbrella-shaped open crown. It often resembles a leguminous species at a distance, especially when in flower. It is adapted to arid, sandy conditions. It is a fast growing tree and has been reported to grow to 4-7 m in one year in areas receiving less than 400 mm of rainfall per year (Emongor, 2009; Odee, 1998).

*M. oleifera* is native to the Sub-Himalayan region of northwest India, Arabia, and possibly Africa and the East Indies, but is now naturalized in most countries of the world including Madagascar, Oman, Qatar, Saudi Arabia, Yemen, Southeast Asia, Hawaii (USA), the Pacific and Caribbean Islands and South America (Morton, 1991; ICRAF, 2001). It is now widely cultivated and naturalized in tropical Africa (Benin, Burkina Faso, Cameroon, Chad, Gambia, Ghana, Nigeria, Guinea, Senegal, Niger, Mali, Liberia, Senegal, Togo, Sierra Leone, Kenya, Tanzania, Uganda, Sudan, Rwanda, Zimbabwe, Malawi, Botswana, Republic of South Africa, etc.), tropical America, Sri Lanka, India, Malabar, Bangladesh, Afghanistan, Pakistan, Thailand, Vietnam, Mauritania, Myanmar, Marshall Islands, Haiti, Malaysia and the Philippine Islands.

Moringa has several common names based on locality and uses. It is commonly known as the “horseradish” tree (Florida) and this arises from the taste of a condiment prepared from its roots. Its other synonym is the “drumstick” tree (India), called so because of the shape of its pods (Nautiyal and Ventakataraman, 1987). In the Philippines, where the leaves of the moringa are cooked and fed to babies it is called “mother’s best friend” and “malunggay” (Tagalog). Other names for moringa include the benzolive tree (Haiti), nébéday (Senegal), aleco (Konsogna), ben oil tree (English), cabbage tree (English), drumstick (English), clarifier tree (English), saragvo (Gujrati), ewe-igbale (Yoruba), kalan'gi (Hamer-Bena), Motlhapametsi (Botswana), meelsakboom (Afrikaans), mlonge or mzunze (Swahili), munga or sajna (Hindi, Bengali), nugge (Kannada), shevga (Marathi), shobhanjana (Sanskrit), munaga (Telgu), murungai (Tamil), sheng (Marathi), zogallagandi (Hausa), and “miracle tree”.

Since moringa is fast growing, drought tolerant and easily adapted to varied ecosystems and farming systems, it can occupy a unique and consistent position in the vegetable industry of any country in the tropics. Its many different uses, its free flowering nature and the ease with which it propagates through sexual and asexual means and its low demand for soil nutrients and water after being planted make its production, management and adoption easy. Therefore, concerted effort should be put to promote its introduction, conservation, evaluation and breeding in Africa in order to fight poverty, food insecurity and disease. In India where commercial production of moringa occurs, the annual net income that small farmers get from moringa cultivation is around US$ 1500/ha (Rajangam et al., 2001). Introduction of moringa into any farm which has a biodiverse environment will be beneficial to both the owner of the farm and the surrounding ecosystem.

Despite the numerous uses of moringa – it’s one of the most used underutilized tropical crops – the agronomic aspects of the crop are lacking. The purpose of this review is to provide information to the scientific community on the potential of moringa as an environmentally friendly source of pharmaceuticals, dyes, biofuel, human food, animal and fish feed, and water purification products. Some information may not have been subjected to rigorous scrutiny of scientific peer review. For example, the medicinal applications to humans may not have been fully substantiated by pharmacological and clinical research. This does not necessarily mean that it does not work. Rather it implies that the mechanism of how exactly it works is not yet fully understood. More rigorous study is required in order to achieve a level of proof required for full biomedical endorsement of moringa, for example as a cancer preventative plant. The information contained herein should challenge the medical and clinical community to give moringa the scientific study that it deserves.

## NUTRITIONAL PROPERTIES AND USES OF MORINGA

Most literature seems to agree on the nutritional benefits of moringa. As the tree produces leaves during the dry season and during times of drought, it is an excellent source of green vegetable when little other food is available. The leaves provide many necessary vitamins and minerals and can be eaten cooked or dried. It has been reported that 25 g daily intake of moringa leaf powder will give a child 42% protein, 125% calcium, 61% magnesium, 41% potassium, 71% iron, 272% vitamin A and 22% vitamin C (Folkard and Sutherland, 1996). The nutritional composition of moringa leaves, pods and seeds reported in literature is indicated in Table 20.

The leaves and branches may be used for fodder when nothing else is useable, and the high nutrient content of the leaves would make it a prime candidate to incorporate into mulching system if the leaves are in abundance and not required as a human food source. In addition to the leaves, the pods or drumsticks can be sold commercially. In India the pods are canned and exported all over the world. Many ethnic grocery stores stock various parts of the tree (Njenga, 1996). Most of the tree is edible: the tuberous root cores can be substituted for horseradish; the bark (ben gum) can be used as seasoning; and the leaves, young shoots, and fresh or canned fruits can be used as vegetables or pickles and in soups and sauces rich in protein, calcium, phosphorus, vitamins A and C, carotene, and amino acids methionine and cysteine (Price and Davis, 2000). The flowers with their radish-like flavour can be eaten or used to make tea. The flowers also produce good honey. The seeds can be consumed fresh as peas; or pounded, roasted, or pressed into a sweet, nondesicating oil (ben oil) of high quality. This oil is used in art, salads, soap, smoke-free lamp fuel, and hair dressing; as a fine lubricant or purgative; and as a fixative for volatile odourous substances in perfumery (Folkard and Sutherland, 1996; Price and Davis, 2000).

## NUTRITIONAL AND NUTRACEUTICAL PROPERTIES OF MORINGA

Moringa leaves are eaten as a vegetable either as a salad or cooked, and in soups and sauces (ICRAF, 2001; Bosch, 2004). The leaves have been reported to increase breast milk in nursing mothers (ICRAF, 2001). The leaves have been reported to treat at least 300 diseases (ICRAF, 2001; Price and Davis, 2000; Tania, 2007; Duke, 1983). Some of the benefits of moringa leaves include that it gives a feeling of wellness and promotes energy, yet this is not a sugar based energy (Tania, 2007; Duke, 1983); increases natural body defense and stimulates metabolism (Tania, 2007; Duke, 1983); stimulates the cell structure of the body (Folkard and Sutherland, 1996); rich in vitamin A, provides nourishment to the eyes and brain (Makkar and Becker, 1997; Oduro et al., 2008); balances level of cholesterol (Tania, 2007; Duke, 1983); balances level of sugar (Fuglie, 2000); rich in anti-oxidants (Njenga, 1996), beautifies the skin and lowers the appearance of fine lines and wrinkles (Folkard and Sutherland, 1996); improves functioning of kidney and liver (Tania, 2007; Duke, 1983); promotes healthy digestion, body’s immune system, anti-inflammatory features; heals arthritis pain, tumors and ulcers (Tania, 2007; Duke, 1983); balances hormone and gland system (Tania, 2007; Duke, 1983); detoxifies body from poisons; helps relax and promotes good night sleep; and purifies water (Tania, 2007; Duke, 1983).

**Table 20: Nutritional composition of pods, leaves and seed of *Moringa oleifera*. Analysis of moringa pods, fresh leaves, dried leaf powder and dried seed per 100 g of edible portion**

(Source: Emongor, 2009; Anhwange et al., 2004; Anwar and Rashid, 2007; Anwar et al., 2006; Fuglie, 2000; Makkar and Becker, 1997; Oduro et al., 2008)

| Variable | Pods | Fresh leaves | Leaf powder | Seeds |
|---|---|---|---|---|
| Moisture (%) | 86.7-88.2 | 74.4-79.14 | 7.5 | 2.03-8.9 |
| Calories | 26.0-37 | 92 | 205-306 | |
| Protein (g) | 2.1-2.5 | 6.7-9.4 | 23.2-35 | 29-42 |
| Fat (g) | 0.1-0.2 | 1.4-1.7 | 2.2-2.3 | 29.7-42 |
| Carbohydrate (g) | 8.5 | 1.3-14.3 | 31.2-45 | |
| Fibre (g) | 3.2-4.8 | 0.9-3.5 | 10-19.3 | 6-10 |
| Minerals or ash (g) | 2.0 | 2.3 | 7.13-8 | 3.6-9.01 |
| Ca (mg) | 30 | 185-440 | 1636-2213 | 83.75 |
| Mg (mg) | 24-45 | 24-147 | 316-474 | 251.3 |
| P (mg) | 50-110 | 70-125 | 125-316 | |
| K (mg) | 259 | 259-275 | 1324-1970 | 36.53 |
| Cu (mg) | 3.1 | 1.1-1.3 | 0.57-0.96 | |
| Fe (mg) | 0.4-5.3 | 4-7 | 22.2-37 | |
| S (mg) | 137 | 137 | 870 | |
| Mn (mg) | - | - | 6.0-10.8 | |
| Zn (mg) | 0.4 | 0.6 | 1.9-3.1 | |
| Na (mg) | - | - | 116-273 | 22.5 |
| Oxalic acid (mg) | 10 | 101 | 1.6% | |
| Vitamin A-β-carotene (mg) | 0.11 | 6.8 | 16.3 | |
| Vitamin B-choline (mg) | 423 | 423 | - | |
| Vitamin $B_1$-thiamine (mg) | 0.05 | 0.21-0.3 | 2.64 | |
| Vitamin $B_2$-riboflavin (mg) | 0.07 | 0.05-0.7 | 20.5 | |
| Vitamin $B_3$-nicotinic acid (mg) | 0.2 | 0.8-2.2 | 8.2 | |
| Vitamin C-ascorbic acid (mg) | 120 | 220-864 | 17.3 | |
| Vitamin E-tocopheral acetate (mg) | - | - | 113 | 95.85-134.2 |
| Arginine (g/16 g N) | 3.6 | 6.0 | 1.33% | 8.00 g |
| Histidine (g/16 g N) | 1.1 | 2.1 | 0.61% | 2.20 g |
| Lysine (g/16 g N) | 1.5 | 4.3 | 1.32% | 3.21 g |
| Tryptophan (g/16 g N) | 0.8 | 1.9 | 0.43% | - |
| Phenylalanine (g/16 g N) | 4.3 | 6.4 | 1.39% | 4.24 g |
| Methionine (g/16 g N) | 1.4 | 2.0 | 0.35% | 1.00 g |
| Threonine (g/16 g N) | 3.9 | 4.9 | 1.19% | 3.03 g |
| Leucine (g/16 g N) | 6.5 | 9.3 | 1.95% | 5.74 g |
| Isoleucine (g/16 g N) | 4.4 | 6.3 | 0.83% | 4.01 g |
| Valine (g/16g N) | 5.4 | 7.1 | 1.06% | 3.05 g |
| Cystine (g) | - | - | - | 2.09 |
| Glutamic acid (g) | - | - | - | 14.43 |
| Aspartic acid (g) | - | - | - | 6.88 |
| Serine (g) | - | - | - | 4.22 |
| Glycine (g) | - | - | - | 4.96 |
| Alanine (g) | - | - | - | 3.22 |
| Proline (g) | - | - | - | 2.09 |
| Tryrosine (g) | - | - | - | 2.37 |

## NUTRACEUTICAL AND MEDICINAL PROPERTIES AND USES OF MORINGA

Moringa species are rich in glucosinolates, isothiocyanates and phenolics (Akhtar and Ahmad, 1995; Abrams et al., 1993; Abuye et al., 1999; Fahey et al., 2001; Anwar and Bhanger, 2003; Bennett et al., 2003). Moringa contains 4-(4′-O-acetyl-α-L-rhamnopyranosyloxy)-benzylisothiocyanate, 4-(4′-O-acetyl-α-L-rhamnopyranosyloxy)-benzylglucosinolate, 4-(α-L-rhamnopyranosyloxy)-benzylisothiocyanate, 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate (leaves, roots, seeds, bark), benzyl glucosinolate (roots), kaempferol-3-O-glucoside, kaempferol-3-O-(6-malonyl-glucoside), quercetin-3-O-glucoside, quercetin-3-O-(6-malonyl-glucoside), 3-caffeoylquinic acid, 5-caffeoylquinic acid, β-sitosterol, zeatin, niazimicin and pterygospermin (leaves).

The phytochemicals of moringa that are reported to have antihypertensive, anticancer, antibacterial, antipyretic, antiepileptic, anti-inflammatory, antiulcer, antispasmodic, antiherpes simplex virus type 1 (HSV-1), diuretic, cholesterol lowering, antioxidant, antidiabetic, hepatoprotective, antifungal, and cardiac and circulatory stimulants activity include 4-(4′-O-acetyl-α-L- rhamnopyranosyloxy)-benzyl isothiocyanate (Abrams et al., 1993), 4-(α-L-rhamnopyranosyloxy)-benzyl isothiocyanate (Abuye et al., 1999), niazimicin (Akhtar and Ahmad, 1995), pterygospermin (Anderson and Bell, 1986), benzyl isothiocyanate (Anwar and Bhanger, 2003) and 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate (Asres, 1995).

Moringa has long been recognized by folk medicine practitioners as having value in tumor therapy (Hartwell, 1967-1971). The phytochemicals 4-(4′-O-acetyl-α-L-rhamnopyranosyloxy)-benzylglucosinolate and 4-(α-L-rhamnopyranosyloxy)-benzyl isothiocyanate from moringa have been examined for their cancer preventive potential (Fahey et al., 2004). The moringa phytochemicals 4-(4′-O-acetyl-α-L-rhamnopyranosyloxy)-benzylglucosinolate and niazimicin have been shown to be potent inhibitors of phorbol ester (TPA)-induced Epstein-Barr virus early antigen activation in lymphoblastoid (Burkitt's lymphoma) cells (Murakami et al., 1998; Guevara et al., 1999). Niazimicin is reported to inhibit tumor promotion in a mouse two-stage DMBA-TPA tumor model (Murakami et al., 1998). Eating of moringa pod extracts has been reported to prevented skin tumor development (Bharali et al., 2003).

Different parts of moringa also contain a profile of important minerals, vitamins, proteins, amino acids, and caroteniods (β-carotene or pro-vitamin A). The benefits for the treatment or prevention of disease or infection may accrue from either dietary or topical administration of moringa preparations (extracts, decoctions, poultices, creams, oils, emollients, salves, powders, porridges, pickles).

Moringa herbal extracts have been shown to improve the health conditions of HIV positive people by increasing the CD4 cells and lowering virus counts (Tian, 2000; Hirt and Lindsey, 2005). Five HIV positive patients who used moringa and *Artemisia annua* as tea three times a tea for two years turned HIV negative (Hirt and Lindsey, 2005). With the high levels of HIV in Africa, moringa can help in improving the immune system by increasing the CD4 cells and lowering the virus counts.

Moringa has been reported to be used in the treatment of diabetes/hypoglycemia (Williams and Lakshminarayanan, 1993; Asres, 1995; Makonnen et al., 1997; Kar et al., 2003; Gupta and Mazumbar, 1999), viral diseases such as herpes simplex virus type 1 (HSV-1) (Lipipun et al., 2003), warts (Fuglie, 1999), HIV-AIDS (Abrams et al., 1993; Prazuk, 1993) and Epstein-Barr virus (Murakami et al., 1998), bacterial diseases such as dental carries (Fuglie, 1999), syphilis (Fuglie, 1999), typhoid (Fuglie, 1999) and urinary tract infection (Shaw and Jana, 1982) and parasites such as helminthes (Fuglie, 1999), schistosomes (Olsen, 1987) and trypanosomes (Mekonnen et al., 1999). Numerous studies report a variety of detoxication and

antioxidant enzymes and biomarkers as a result of treatment with moringa or with phytochemicals isolated from moringa (Fahey et al., 2004; Faiz et al., 1994; Kumar and Pari, 2003; Rao et al., 1999).

There are widespread claims of the medicinal effectiveness of various moringa tree preparations in literature (traditional medicine, tribal lore, oral histories and anecdotes), but they lack scientific proof on the efficacy of these traditional cures (Sampson, 2005; Talalay and Talalay, 2001). Much more controlled basic and applied research especially clinical trials in human beings is required in order to achieve a level of proof required for full biomedical endorsement of moringa as a cancer preventative, antibiotic, antifungal, anti-inflammatory, anti-epileptic, antidiabetic, etc. plant. This does not mean that the various moringa preparations do not work. They do work, but clinical scientific evidence is needed.

## INDUSTRIAL USES OF MORINGA OIL

The oil content of de-hulled seed is approximately 42%. The oil is brilliant yellow. It is used as a lubricant for delicate machinery such as watches and clocks because it has little tendency to deteriorate and become rancid and sticky (Ferrao and Ferrao, 1970). Moringa oil seed is also useful as vegetable cooking oil. The oil is also known for its ability to absorb and retain volatile substances and is therefore valuable in the perfume industry for stabilizing scents. The free fatty acid content varies from 0.5 to 3%. The moringa seed oil contains approximately 13% saturated fatty acids and 82% unsaturated fatty acids. It has a particularly high level of oleic acid (73%) (Table 21). Other vegetable oils normally contain only about 40% oleic acid.

## WATER PURIFICATION

Seeds can be used to purify water, which is a very special property or use of the tree seeds. The capacity of seeds to purify water is a very important trait because it enables people in rural areas where there are no water purifying facilities to have the chance to use pure water and thus reduce the risks associated with drinking dirty water. When pounded moringa seeds are added to muddy water, the water is purified after one hour and looks as if it has been filtered with a chemical product such as aluminum phosphate, a common water purifier (Duke, 1983). Only one seed is required per litre for slightly contaminated water and two seeds for very dirty water (Duke, 1983). The dry seed suspension of moringa is known to be a natural coagulant and coagulant aid (Jahn, 1986; Folkard et al., 1989; Kaser et al., 1990; Sani, 1990; Bina, 1991). Coagulation and bacterial reduction studies on turbid Nile water in the Sudan using moringa seeds showed turbidity reduction of 80-99.5% paralleled by a bacterial reduction of 1-4 log units (90-99.9%) within the first one to two hours of treatment, the bacteria being concentrated in the coagulated sediment (Madsen et al., 1987). Moringa has been compared to alum in its effectiveness in removing suspended solids from turbid water, but with a major advantage also of softening hardwater (Muyibi and Evison, 1995). Because it can be produced locally, using moringa would save foreign exchange and generate farm and employment income (Meitzer and Price, 1996). The edible oil produced from the seeds can also be used in lubrication, soaps and cosmetics and as a source of medicine (Dahot and Memon, 1985).

Moringa seeds contain between 30-42% oil and the press cake obtained as a by-product of the oil extraction process contains a very high level of protein (Foidl et al., 2001). Some of these proteins are active cationic polyelectrolytes having molecular weights between 7-17 Kdalton. The cationic polyelectrolytes neutralize the colloids in muddy or dirty water since the majority of these colloids have a negative electrical charge. This protein can therefore be used as a non-toxic natural polypeptide for sedimenting mineral particles and organics in the purification of drinking water, for cleaning vegetable oil, or for sedimenting fibres in the juice and beer industries. It thus works as a primary coagulant as natural bridges are continuously

formed between the colloid particles. In contrast, industrial coagulants such as alumina can be toxic (Foidl et al., 2001). Their proper use requires qualified personnel and the majority of underdeveloped countries do not have the means of producing them. In addition, these industrial coagulants are expensive and represent a considerable drain on the hard currency reserves of developing countries.

**Table 21: The physico-chemical properties and fatty acid composition of moringa seed oil**

(Source: Anwar and Rashid, 2007; Foidl et al., 2001; Abdulkarim et al., 2005; Nzikou et al., 2009).

| Property | Value |
|---|---|
| Saponification value | 181.4-188.36 |
| Iodine value | 65.58-69.45 |
| Density at 20-24°C (g/ml) | 0.89737-0.9032 |
| Refractive index at 20-40°C | 1.457-1.4670 |
| Solidification point (pour point °C) (Method D-97) | 6 |
| Free fatty acids (%) | Up to 2.98 |
| **Fatty acid composition (%)** | |
| Lauric | Trace |
| Myristic | 0.05-0.08 |
| Pentadecanoic | Trace |
| Palmitic | 4.75-7.8 |
| Palmitoleic | 1.22-1.48 |
| Margaric | 0.08 |
| Margaroleic | 0.05 |
| Stearic | 5.42-7.6 |
| Oleic acid (C18-1) | 67.79-76 |
| Linoleic | 0.46-0.76 |
| Linolenic | 0.09-0.14 |
| Arachidic | 3.39-4.08 |
| Gadoleic acid | 2.2-2.24 |
| Behenic | 5.33-9.03 |
| Erucic | 0.13-0.14 |
| Lignoceric | 0.92-1.12 |
| Cerotic | Trace |
| Other fatty acids | 0.1-0.2 |
| Triolein (main triacylglycerol) | 36.7 |

Moringa seeds can be used for the final treatment in wastewater treatment units. In oxidation lagoons, 80% of the oxygen demand of water is caused by unicellular algae. These algae also contain between 40-60% of the nitrogen and phosphorus found in the pre-treated wastewater. To avoid eutrophication of rivers or lakes by the release of high loads of both phosphorus and nitrogen, the seeds of moringa can be used to coagulate algae and remove them by sedimentation (Foidl et al., 2001). Up to 98% of the algae can be removed by this treatment. After sedimentation the residual wastewater was both clear and transparent. The treatment also reduced the oxygen demand of the water by approximately 70% and its content of both phosphorus and nitrogen by 60% (Foidl et al., 2001). The algae recovered by sedimentation have a protein content of about 46% after drying and pulverization and can be used as a protein supplement for cows, pigs, chicken and even shrimps, thereby reducing the cost of feeding substantially (Foidl et al., 2001).

## PLANT GROWTH ENHANCERS

The extract obtained from the leaves of moringa in 80% ethanol contains the phytohormones cytokinins (Foidl et al., 2001) such as zeatin, dihydrozeatin and zeatin riboside (Price and Davis, 2000). The extract can be used in the form of a foliar spray to accelerate the growth of plants, increasing yields by 25-30% for crops such as onions, bell pepper, soya, maize, sorghum, coffee, tea, chilli, cantaloupe, melons, tomato, sugar cane, black beans and common beans (Price and Davis, 2000; Foidl et al., 2001; Makkar and Becker, 1996). The use of the growth hormone spray from moringa is reported to cause plants (peanut, soy bean, maize, sorghum, tomatoes and capsicum) to be firmer and more insect pest and disease resistant (Foidl et al., 2001). The extract can be obtained either through press extraction or by using an ultra-turrax and filtering 20 g of tender leaves in a total volume of 675 ml of 80% aqueous ethanol (Foidl et al., 2001). Spraying the leaves of plants with the moringa extract prepared in 80% ethanol and then diluted with water produced notable effects such as longer, more vigorous life-span, heavier roots, stems and leaves, bigger fruits and higher sugar content levels (Foidl et al., 2001). This foliar spray should be used in addition to other good agricultural practices such as proper fertilizer or manure application, watering and other cultural practices.

## GOOD AGRICULTURAL PRACTICES (GAP) IN MORINGA CULTIVATION

Good agricultural practices is the application of available knowledge to the utilization of the natural resource base in a sustainable way for the production of safe, healthy food and non-food agricultural products, in a humane manner, while achieving economic viability and social stability. The principal is one of knowing, understanding, planning, measuring, recording, and managing to achieve identified social, environmental and production goals or objectives. This requires a sound and comprehensive management strategy and the capability for responsive tactical adjustments as circumstances change. Success depends upon developing the skill and knowledge bases, on continuous recording and analysis of performance, and the use of expert advice as required. GAPs may be applied to a wide range of farming systems and at different scales. They are applied through sustainable agricultural methods, such as integrated pest management, integrated fertilizer management and conservation agriculture. They rely on four principles: 1) economically and efficiently produce sufficient (food security), safe (food safety) and nutritious food (food quality); 2) sustain and enhance natural resources; 3) maintain viable farming enterprises and contribute to sustainable livelihoods; 4) meet cultural and social demands of society.

## GERMPLASM AND DIVERSITY

The 13 species of the genus *Moringa* are known. The Horn of Africa is native to species of *Moringa*, suggesting that the Horn of Africa is the centre of *Moringa* diversity. The *Moringa* species found in the Horn of Africa are: *Moringa stenopetala* (Kenya and Ethiopia), *M. peregrine* (Kenya, Ethiopia and Somalia), *M. arborea* (northeastern Kenya), *M. borziana* (Kenya and Somalia), *M. longituba* (Kenya, Ethiopia and Somalia), *M. pygmaea* (northern Somalia), *M. rivae* (Kenya and Ethiopia) and *M. ruspoliana* (Kenya, Ethiopia and Somalia). The other moringa species and their nativity are: *M. drouhardii* (Madagascar), *M. hildebrandtii* (Madagascar), *M. ovalifolia* (southwest Angola), *M. concanensis* (India) and *M. oleifera* (India).

*Moringa oleifera* exhibits considerable genetic variability in weight of cotyledons, seed size, number of pods/tree, pod length, pod appearance and pod quality, yield (seeds, pods and leaves), phenology, tannins and other anti-nutritional factors (Jahn, 1986; Morton, 1991; Foidl et al., 2001; Duke, 1987). Some of this variability is genetically or environmentally controlled, and may result from long-term vegetative reproduction, as is customary when producing annual moringa plants (Jahn, 1986). Pods can be sweet to bitter. There are only a

few named varieties of moringa in India (Rajangam et al., 2001). One variety named Jaffna (yazhpanam) is grown in various parts of southern India and produces fruits of 60-90 cm in length with soft, tasty flesh (Rajangam et al., 2001). One of the best Indian cultivars, Bombay, has curly fruits. Sri Lanka has several named varieties of moringa such as Chavakacheri (producing fruits 90-120 cm long), Chemmurungai (red tipped fruits; flowers throughout the year and yields heavy crops) and Kadumurungai (produces small inferior quality pods) (Kadhar and Shanmugavelu, 1982). In Kenya, four varieties of *Moringa oleifera* have been identified and named as Likoni, Mbololo, Kibwezi and Kitui (Odee et al., 2001). They reported that molecular analysis showed that Kibwei provenance had the largest population in Kenya and the most genetically diverse. Because it is a cross-pollinated tree, high heterogeneity in form and yield is common; genotypes exist in varied geographical areas to be harnessed for crop improvement programmes (Sundarajan et al., 1970). Research in genetic variation in populations from Kenya, Malawi and India concluded that germplasm from at least two sources had been introduced into Kenya (Bosch, 2004). The high level of variation among moringa populations suggests that provenance source is important in the conservation and exploitation of genetic resources. *Moringa* species are widespread in the tropics and subtropics and there are numerous accessions in genebanks.

## BREEDING

In India, "Jaffna" types are popular for their long fruits (60-100 cm long). In India, two improved annual moringa varieties PKM-1 and PKM-2 have been released within a span of 10 years, for commercial cultivation (Rajangam et al., 2001; Sathashakthi, 1999). The characteristics of PKM-1 annual moringa are as follows: evolved through pure line selection; seed propagated; dwarf-medium in stature; pods are 60-70 cm long with 6.3 cm girth and weigh 120 g; bears 220-250 fruit/tree; pod yield is 50-54 t/ha; suitable for ratoon crop; low incidence of insect pests and diseases; and suitable for varied soil types (freely drained) in tropical plains. The characteristics of PKM-2 annual moringa are as follows: this is a hybrid derivative developed by a cross between MP 31 x MP 28; medium tall stature; propagated by seed; pods are 125 cm long with 8.3 cm girth and weigh 280 g; pods are less seeded and more fleshy; suitable for tropical plains; can be grown as an intermediate crop in coconut and tropical fruit orchards at pre-fruit-bearing stage; bears 240 fruit/tree; and pod yield is 98 t/ha. Many farmers in India now grow the varieties PKM-1 and PKM-2 as annuals. The extent of variability in the seedling populations of the annual moringa has been studied (Suthanthirapandian et al., 1989). Among the nine traits studied, number of flowers per inflorescence (19-126), fruit weight (25-231.5 g) and pod number per plant (1-155) showed significant variation in terms of observed variance, standard deviation and coefficient of variation (Suthanthirapandian et al., 1989). In Africa, the most important selection criteria have been high leaf, fruit, and seed yield, and seed oil content. There is potential for hybridization with other *Moringa* species. *Moringa stenopetala* contains flocculating agents similar to those in *Moringa oleifera* and produces larger seeds, so it may be possible to increase yields by hybridization with this species. It may be possible to increase the oil yield of *Moringa oleifera* by producing hybrids with *Moringa peregrina* (Forssk.) Fiori, which has higher oil content (approximately 50%).

Polyphenols, commonly known as tannins, occur widely in many different plants, especially those from tropical regions. Their consumption by animals has adverse effects on productivity and health. Fresh moringa leaves are reported to contain neglible amounts of tannins (1.4%) and condensed tannins are undetectable (Makkar and Becker, 1998), while the total phenol content in is in the range of 2.7-3.4% (Gupta et al., 1989). At this concentration, these simple phenols do not produce any adverse effects when eaten by animals. The other anti-nutritional factors reported in fresh moringa leaves are the saccharides raffinose and stachyose which produce flatulence in monogastrics. Raffinose and stachyose comprise 5.6% of dry matter of unextracted moringa leaves (Gupta et al., 1989). With good agricultural practices the tannins and the other anti-nutritional factors in moringa can be reduced through breeding and

selection of provenances having negligible concentrations of tannins, phenols, oxalates, glucosinolates and the saccharides raffinose and stachyose.

## PLANTING MATERIAL AND NURSERY MANAGEMENT

*Moringa oleifera* can be propagated by seed, stem cuttings and tissue culture. Moringa can easily be grown from seeds and stem cuttings. Seeds can be planted directly in the field or can be planted in a nursery (use of polyethylene bags is recommended). In direct planting, the seed should be planted in already dug holes of 50 x 50 x 50 cm to ensure accelerated growth of the seedlings. For intensely managed seedlings such as annuals, 10 kg of farmyard manure and 50 g N/hole should be added. The seed should be planted in the centre of the hole. Seeds should be planted 2 cm deep and germination takes place within 7-20 days depending on the growth medium temperature and seed viability. Germination percentage is high on freshly harvested seed (80-90%); however, the seed looses viability fast. After one year germination capacity is about 46-50%, and after 2 years, germination capacity can be 0%. If the seeds are planted in the nursery they should be transplanted after 2-3 months (seedlings average 25-40 cm in height) after emergence.

Cuttings 45-100 cm long and 4-10 cm wide should be taken from the woody parts of the branches. The wood should be from the previous year's growth. The cuttings can be cured for three days in the shade and then planted in the nursery or field. Direct planting from stem cuttings should coincide with the rainy season. Trees grown from cuttings start flowering 6-12 months after planting depending on climatic and cultural conditions. In monoculture cultivation, moringa should be spaced at 2.5-5 m x 2.5-5 m depending on the intended use, agronomic practices and climatic condition (Ramachandran et al., 1980). Some farmers also plant moringa at a spacing of 0.7-1 m x 0.7-1 m for short-term production of leaves (Fuglie, 1999). In India, the plant spacing used is 2.5 x 2.5 m, giving a population of 1600 plants/ha (Rajangam et al., 2001). In Tanzania, moringa is spaced at 3 x 4 m (833 trees/ha) for the production of seed for oil and flocculants (Foidl et al., 2001). In alley cropping an intra-row spacing of 2 m is recommended (Bosch, 2004). In the wet season cereals are grown between the rows, while in the dry season vegetables are grown.

## CROPPING SYSTEM

The moringa tree requires little care once established. If planting is done during the dry season half-shade should be provided and watering (using good quality water free from pathogens, low in total dissolved solids and sodium adsorption ratio of less than 3) be done regularly until the trees are established (Duke, 1987). Fertilizer or properly composted manures or municipal biosolids application is essential to obtain good yields of leaf, pod or seeds. In order to promote branching, increase leaf production and facilitate harvesting, pollarding, coppicing and lopping or pruning are recommended. Because its shade can be controlled well, moringa is suitable for planting in alley cropping and in vegetable gardens. When trees reach 1.5-2 m prune at 1 m above the ground once or twice per year to promote leaf production or biomass. In India, the seedlings are pinched when they reach a height of 75 cm in order to promote lateral branching and reduce plant height (Rajangam et al., 2001). In addition, pinching reduces damage due to strong winds and makes harvesting easier. Early pinching (60 days after sowing) of the apical buds (growing tips) has been reported to be better than pinching after 90 days of sowing for obtaining higher leaf and fruit yield (Vijayakumar, 2000). After pruning, it takes 3-4 weeks before the leaves can be harvested depending on water availability, fertilizer or manure application (soil fertility) and climatic conditions especially temperature. Weed control should be done manually by hoeing between the rows and trees.

Application of $GA_3$ at 20 mg $L^{-1}$ 90 days after sowing increased all the pod variables such as length, specific gravity, seed number, flesh content and pulp compared to untreated moringa plants (Vijayakumar, 2000).

**PESTS AND DISEASES**

Caterpillars are the major insect pests of moringa and timely pruning provides some control. The hairy caterpillar *Eupterote molifera* can cause defoliation and requires integrated pest management (Duke, 1983). Termites may also be a problem especially in the semi-arid and arid areas or regions. Fruitflies (*Gitona* spp.) have been reported to infest the fruits which dried out at the tip and rotted (Duke, 1983). Leaves of young plants and freshly planted stumps are attacked by several species of weevils (*Myllocerus discolor* var. *variegatus*, *M. 11-pustulatus*, *M. tenuiclavis*, *M. viridanus* and *Ptochus ovulum*) (Anjaneya and Regupathy, 1992; Ragumoorthi and Subha, 1998). Moringa is also parasitized by the flowering plant, *Dendrophthoe flacata.* Fungi which attack the horseradish-tree include: *Cercospora moringicola* (leaf spot), *Sphaceloma morindae* (spot anthracnose), *Puccinia moringae* (rust), *Oidium* spp. and *Polyporus gilvus* (Anjaneya and Regupathy, 1992). In India, developing fruit is reported to be attacked by the fruit fly (*Gotona distigmata*) which was controlled effectively by integrated pest management (IPM) measures (Anjaneya and Regupathy, 1992; Ragumoorthi and Subha, 1998). The IPM package included: a) application of fenthion 80 EC, 0.04% during the vegetative and flowering stage; b) application of nimbecidine, 0.03% at 150 mg $L^{-1}$ during 50% fruit set and 35 days after; c) soil application of neem seed kernel extract at 2 litres per tree at 50% fruit set; and d) weekly removal of affected fruit (Anjaneya and Regupathy, 1992; Ragumoorthi and Subha, 1998).

**PLANT NUTRITION**

Moringa trees are generally grown successfully without fertilizers. In southern India, ring trenches are dug about 10 cm from trees during the rainy season and filled with green leaves, manure and ash, and then covered with soil. This promotes higher leaf, seed or pod yield (Ramachandran et al., 1980). If fertilizers are applied, the crop requires 44:16:30 g of N:P:K per tree, respectively, 75 days after sowing (Rajangam et al., 2001). Nitrogen at 44 g/tree must be applied as top dressing at the start of flowering (Suthanthirapandian et al., 1989). Integrated nutrient management in annual moringa comprising of organic manures, biofertilizers and varying levels of N, P and K has been studied (Beaulah et al., 2001). The results obtained showed a positive response of moringa to the application of manures and fertilizers. Initial vigour was higher in treatment with poultry manure (500 g/hole) + neem cake (250 g/hole) + panchakavya (2%) spray along with 150:150:100 g N:P:K/tree. In ratoon crops, similarly, the same treatment resulted in early and vigorous growth.

In annual moringa, when the harvesting period is over, the trees are pruned to a height of 1 m above the ground for ratooning. The ratoon plants develop new shoots and start bearing pods 4-5 months after pruning. Three ratooning operations are recommended during the production cycle in India, thus at months 9, 17 and 25, respectively, after each harvest (Rajangam et al., 2001). During each pruning operation, the plants should be supplied with the recommended level of N, P, and K along with 20-35 kg of farm yard manure per tree. Perennial moringa types can also be pruned back to a height of 1 m from the ground, followed by application of 20-35 kg of manure plus 44:16:30 g of N:P:K of inorganic fertilizers/tree.

**IRRIGATION**

Growing moringa plants may not require watering except during hot weather when they may be irrigated once a week. Annual moringa responds positively to irrigation and the yield can be doubled (leaves and pods) by drip irrigation as compared to rain-fed crops (Rajakrishanamoorthy et al., 1994).

## POST-HARVEST MANAGEMENT

### Harvesting

Fruit, leaves, pods and seeds can be harvested as desired according to the production system, agronomic or cultural and climatic conditions. Depending on climatic conditions moringa trees can fruit twice per annum. Leaf harvesting can start 10-14 weeks after planting or transplanting. Leaves are pulled from the branches, put in clean bags or harvest containers or bins and either transported in clean vehicles (vehicles have to be clean, free from odours, obvious dirt and debris to minimize microbial contamination and maintain high hygiene) to the market to be sold as a fresh vegetable (can be cooked or steamed as a leafy vegetable) or dried and later ground to form leaf powder to be used as tea, seasoning or pickles. Leaf harvesting can be done twice a month. Harvesting of green pods (harvest when the pods snap without leaving strings) can start 7-10 months after planting or transplanting; harvesting of dry fruits for seed about 6-8 weeks later. Perennial moringa types started from cuttings take approximately one year to bear fruit. The yield will generally be low 80-90 fruit/tree/year in the first two years of fruit-bearing. This gradually increases to 500-600 fruit/tree/year.

### Leaf yield

Whether the moringa leaves are produced for human consumption or use as green manure or livestock feed, moringa can be grown intensively with yields of up to 650 t/ha of green matter (Price and Davis, 2000). Biomass production of between 10.4 to 24.7 t/ha on dry matter basis has been reported (Nadir, 2006). A biomass production of 126 t/ha/year on fresh weight basis has also been reported (Becker, 2003). Biomass production in forage trees and shrubs is influenced by several factors such as plant age at the first cutting, cutting height, cutting frequency, plant density, agronomic or cultural practices, climatic factors and season of the year. For example, to get vigorous regrowth of foliage of trees and shrubs after the first cutting, a good root development is required. Cutting forage trees at different seasons of the year (dry season versus wet season) and at different stages of development (flowering versus vegetative) influences subsequent regrowth. Cutting at the beginning of the dry season may result in exhaustion of reserves and replishment of reserves may be restricted by limited moisture availability depending on the soil type and water table of the growing site. On the other hand, trees and shrubs are deep-rooted and therefore may have access to moisture in the deep soil layers. They are also expected to have a large amount of reserves in stems and roots (Stür et al., 1994). The pod and seed yields of moringa have not been reported much in literature. Therefore, agronomic research on oil, pod and seed yield of moringa should be done. However, in Tanzania it is reported that a 4-year-old tree yields 3.3 kg of seed (Bosch, 2004) and a good tree yields 1000 fruit.

### Pod yield

The moringa pod yield varies with the moringa type (annual or perennial), cultural practices (fertilizer application, irrigation, manure application, weeding, etc.), cultivar, tree spacing, production system and climatic conditions. Moringa trees can yield 220-600 pods/tree/year (50-120 t/ha) (Foidl et al., 2001).

### Post-harvest handling and processing

Leaves can be dried and stored. The leaves must be dried and stored under hygienic conditions. Under commercial operations oven drying at 35°C is recommended or the moringa leaves can be dried under shade and hygienic conditions using raised tables with fine gauze while to allow aeration (sun drying causes loss of vitamin A) (Folkard and Sutherland, 1996). The dried brittle leaves are then milled or pounded and shifted to remove leaf stems. The leaf powder should be stored in a sealed clean dark container because light breaks down

vitamin C. The leaves can also be blanched and stored under deep freeze (-18°C) (Wijayawardana and Bamunuarachchi, 2002). The leaves can also be blanched and sulphited and stored at 0°C (Wijayawardana and Bamunuarachchi, 2002). The pods or drumsticks can be blanched and stored at -18°C or the pods can be canned (Wijayawardana and Bamunuarachchi, 2002). For canning the pods should be heated at 121°C for 20 minutes (Wijayawardana and Bamunuarachchi, 2002). However, heating the pods for 20 minutes at 121°C results in 31% loss of vitamin C compared to fresh moringa pods, but the shelf-life of the produce is prolonged and the produce is free from pathogenic micro-organisms (Wijayawardana and Bamunuarachchi, 2002).

For seed production, the pods should be brown in colour and the seed colour should be black for good quality seed with high germination potential (Wijayawardana and Bamunuarachchi, 2002). Harvested pods must be dried for 2 days under shade with good ventilation. The seeds are extracted manually by opening the pods by exerting gentle pressure on them. On opening, the seeds are separated freely. Small, shriveled and damaged seeds must be discarded. Grading of seed can be done using the specific gravity separator. The seeds should have a moisture content of 8% and treated with captan at 2 g/kg of seed (Bosch, 2004). Treated seed can be stored at 0°C for up to 12 months.

## CONCLUSION

The prospects of moringa becoming an important multipurpose crop worldwide are high due to its numerous economic applications and diverse uses. Research on the use of moringa leaf powder in boosting the immune system, particularly of HIV positive patients and on patients that are on antiretroviral (ARVs) drugs, on the functioning of the liver should be done. Cultivar selection and the development of hybrids have great potential. Many of the medicinal applications have not been fully substantiated by pharmacological and clinical research and warrant further research. The industrial demand for *Moringa* oil is likely to increase as biofuel or natural vegetable cooking oil, as novel applications are developed. More research on the agronomy of this crop under good agricultural practices is needed, in order to reap its benefits as food and food ingredients, potential production of antioxidants and pharmaceutical products for local and international markets, water purification, and livestock and fish feed.

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# Towards Good Agricultural Practice to Promote Production and Consumption of Neglected Vegetables: Case of Moringa (*Moringa oleifera*) in Tanzania

**Joseph P. Hella[1]* and Mwantumu S. Omari[2]**

[1]*Agricultural Economist, Sokoine University of Agriculture, P.O. Box 3007, Mororgoro, Tanzania, *Corresponding author (jp_hella@yahoo.co.uk)*
[2]*Agricultural Economist/Food Technologist, Sokoine University of Agriculture, P.O. Box 3007, Mororgoro, Tanzania (tumuomari@yahoo.co.uk)*

**Abstract**

African indigenous vegetables (AIVs) play a highly significant role in food security, income, and health of the many under-privileged communities in both urban and rural settings. Introduction of exotic vegetables has down-played the role of AIVs significantly. However in recent years the important role of AIVs in Tanzania's health, diets and as an income source is greatly promoted particularly through great works at AVRDC-RCA. However more work is needed since many other are still neglected. This paper presents a review of the economics of one neglected tree vegetable crops – moringa (*Moringa oleifera*) – a dominant tree in various farming systems in Tanzania. The discussion is centered on efficacy of this crop, on the use of land, labour and capital inputs versus its social, cultural and economic values within the context of changing environmental resilience and need to adopt Good Agricultural Practice. New production approach to ensure wide spread through demand pull scenario is also presented. The paper concludes that with the current climate change and food security requirements this crop offers a unified solution. The paper calls for an increased effort to bring the crop into large scale cultivation and utilization through promotion and advanced research within the FAO defined GAP framework.

**Keywords:** indigenous & neglected vegetables, moringa, net present value, costs and benefits

## BACKGROUND INFORMATION

### Introduction

Vegetables are of great importance in the tropics and subtropics of Africa in a twofold sense – as food and as commercial products. As food, vegetables can supply an important part of the minerals, vitamins and proteins (King, 1971). Of course, the individual species differ greatly in their nutritional value. The leafy vegetables are especially valuable (containing vitamin K, as well as the other vitamins, whereas the fruit and tuber types contain fewer nutrients, but stimulate the appetite by their colour (tomato, beetroot), smell and taste (cucumbers, radish). In the humid tropics, the leafy vegetables are important sources of protein, which is frequently in short supply. The number of species that are consumed as vegetables in the tropics and subtropics is so large. To them can be added the leaves of many plants which are grown for other purposes (grapevine, cassava, sweet potato, *Colocasia*, *Xanthosoma*, muskmelon, pumpkins, and others).

African indigenous vegetables are considered valuable because of their ability to fit into year-round production systems, their nutritional value, and the danger of their extinction (Schippers, 1997; Grivetti and Ogle, 2000). Many thrive in the harsh conditions that many

Africans confront daily. And many are exceptionally nutritious. Yet most are receiving adequate scientific or institutional support, despite their significance where the needs for food, nutrition, and rural development are perhaps greater than anywhere else. Moringa (*Moringa oleifera*) (*Mlonge* in Kiswahili) belongs to this group.

**Reading from history**

History reveals that the earliest emigrants out of Africa – long before agriculture – found new foods on their journeys. For many thousands of years, hundreds of wild and (in time) cultivated native species complemented each other for continental food supply. Then a pivotal plant migration began. Asian foods wended westward to become new links in the African food chain (sorghum and others took the return route from Africa). Exotic species from Asia – most notably rice, bananas (in their various forms), and sugarcane – began contributing more and more to life below the Sahara. Yet many Africans remained largely dependent on traditional food plants until about five centuries ago, when adventurers and slavers sailing the western seaboard introduced a collection of American crops. These additions notably included maize (corn), cassava (manioc), peanut (groundnut), sweet potato, tomato, common bean, chili peppers, and pumpkin (National Research Council, 2006).

As is common with non-native plants, the new arrivals tended towards robust and productive growth, thus subsequent centuries saw them spread across Africa as farmers integrated these helpful adjuncts into their age-old livelihood strategies. That inevitably meant that more of the traditional contributors fell away from the food supply and the minimization process proceeded. During the colonial era the process of discarding indigenous crops gained further momentum, as the official focus shifted to those familiar crops of mercantile interest, such as cane, chocolate, coffee, cotton, and other durable, transportable, and valuable crops of that sort (National Research Council, 2006). Indeed, during those times subsistence crops were almost entirely neglected in organized agriculture, while valuable exportable cash crops were cultured, harvested, graded, and protected against rodents, insects, and decay with exceptional efficiency and dispatch.

Countries in the elevated central regions – Burundi, Rwanda, Ethiopia, and Kenya – grow potato. Banana dominates Rwanda, and Ethiopia also relies on chickpea and lentil. South Africa recorded its leading vegetable crops as potato, tomato, green mealies (maize), sweet corn, onion, pumpkin, carrot, cabbage, lettuce, and beetroot (National Research Council, 2006). Now here is moringa the wonder tree (Fuglie, 2001). This is a tree that meets all nutritional needs, takes care of medicinal requirements and purifies water. This is what characterizes the moringa tree. For centuries, the natives of northern India and few parts of Africa have known the many benefits of *Moringa oleifera* (Bakhru, 1995). Its uses are as unique as the names it is known by, such as clarifier tree, horseradish tree and drumstick tree (referring to the large drumstick shaped pods). In east Africa it is called “mother's best friend”. Virtually every part of the tree can be used. Native only to the foothills of the Himalayas, it is now found in Africa, Central and South America, Sri Lanka, India, Malaysia and the Philippines. This tree, though little known in the Western world, is nutritional dynamite. There are literally hundreds of uses for this tree (Ramachandran et al., 1980; Fahey, 2005), however, its potential use in Tanzania has not been explored because of limited documentation of the good production practices to be adopted on one part and lack of policy and advocacy.

**THE PROBLEM**

Three things are happening in the current time with respect to agriculture in sub-Saharan Africa. First is the observed climate change, second is the increasing food insecurity and malnutrition problem and third is the need for agricultural practices that address

environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products.

In recent years there has been a growing concern over the phenomena of climate and its effects on agriculture, environment and energy sources that are based on water resources. In our country just like in a number of other countries, climate changes have manifested themselves by extreme fluctuations in patterns and magnitudes with respect to atmospheric temperatures, precipitation, or wind. The challenge lays in forging strategies for managing risk, reducing vulnerability & enhancing agricultural productivity and protecting the environment under a changing climate. The effects of these fluctuations have included changes in the range and distribution of plants and animals, trees blooming earlier, lengthening of growing seasons, extreme periods of heat and cold, storms, and increased prevalence of climate-sensitive diseases such as malaria (Figure 39).

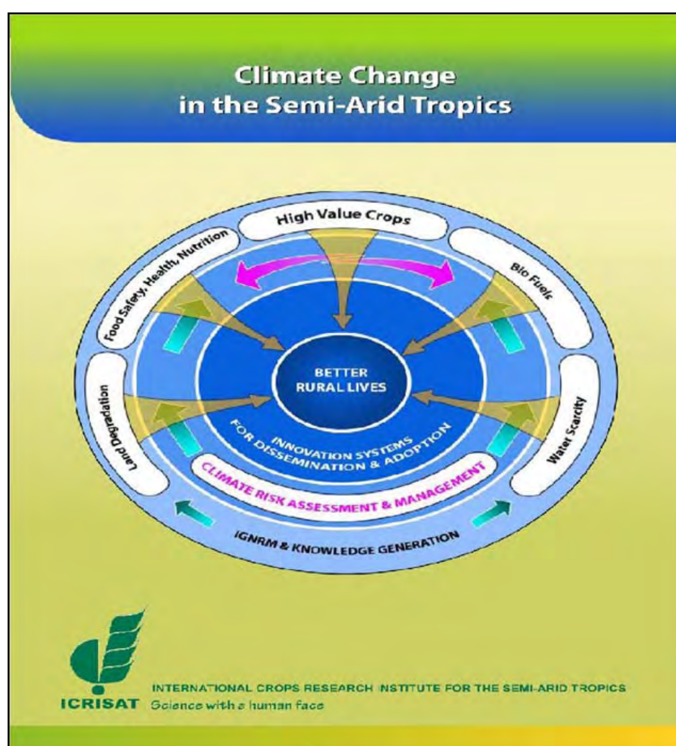


**Figure 39: Requirements for better rural life in semi-arid tropics**

(Source: ICRISAT, India)

These extreme changes signal us to think about going back to basics. African indigenous vegetables are considered valuable because of their ability to fit into year-round production systems, their nutritional value, and the danger of their extinction. However, crops should be selected for domestication only if there is real nutritional or economic need (Swaminathan Research Foundation, 2002).

Another pertinent problem that guided us to come up with this paper is that of food insecurity as explained by increased malnutrition problems in sub-Saharan Africa. This problem is emanated by increased declining soil fertility due to soil erosion, climate change and ill-health problems due to widespread HIV/AIDS pandemic.

Thirdly is the need to adopt Good Agricultural Practices (GAP). Based on the United Nations Food and Agriculture Organization (FAO), GAP are a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-

food agricultural products, while taking into account economical, social and environmental sustainability. Among various crops which fit GAP requirements, moringa is at the top of the list (FAO, 2003). Moringa production and utilization, if collates with GAP, would be optimized through sustainable agricultural methods, such as integrated pest and fertilizer management and conservation agriculture. They rely on four principles:

- Economically and efficiently produce sufficient (food security), safe (food safety) and nutritious food (food quality);
- Sustain and enhance natural resources;
- Maintain viable farming enterprises and contribute to sustainable livelihoods;
- Meet cultural and social demands of society.

The main objective is to present an overview of the economics of AIVs with a focus on the neglected moringa (*Moringa oleifera*) as a model crop, an important but neglected vegetable tree crop within the framework of GAP.

## METHODOLOGY

### Review of literature

Moringa as a vegetable crop has been neglected for several decades, thus there is very limited literature available. Main source was internet based literature that spans across the time horizon. Based on available data, this paper highlights production costs, production methods, labour requirements, husbandry practices, type and price of inputs required that are in accordance to the good practices defined by FAO within the local settings. For comparison purpose, the review to compare moringa with other vegetables touched base on GAP for moringa production within the framework of soil, water, crop and fodder production, animal production, health and welfare, harvesting and on-farm processing & storage, energy and waste management, human welfare, health and safety, wildlife & landscape.

### Benefit cost analysis of growing moringa

The benefit (both tangible and intangible) and cost over time was used to generate information on the cash flow of growing moringa compared to other exotic vegetables i.e. Chinese cabbage. The Net Present Value (NPV)[18] was estimated for a 15 years period at 15% opportunity cost of capital.

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[18] $$NPV = \sum \frac{b_1 - c_1}{(1+i)^1} + \ldots\ldots\ldots\ldots\ldots\ldots + \frac{b_n - c_n}{(1+i)^n}$$

b = stream of benefits

c= stream of costs

i= interest rate (opportunity costs of capital = 15%)

n= time period (15 years)

∑ = Summation sign

b = produced green leaves for human and animal feed, seeds, soil erosion control, wind break, medicinal effect, oil extract from seed,

c = land, farm operations (labour hours, machine hours), farm inputs (seed fertilizer) and opportunity cost of capital investment

Data for developing a cash flow for determining a cost benefit analysis of the specified period of time were established after discussion with Chinese cabbage farmers who have extended production experiences.

## FINDINGS AND DISCUSSION

### Agronomic suitability to local and changing climate

Moringa is an extremely adaptable species. It grows well throughout the warmer climate zones, ranging from subtropical to tropical and from dry savanna to rainforest. While the crop prefers moist situations (such as along waterways and coastal areas), it adapts to climates with several months of drought. Moringa is reported to tolerate annual precipitation of 250-1,500 mm, thus an ideal crop to meet requirements of many farmers in sub-Saharan Africa.

Elevations below 600 m are reported optimal for moringa, however, it thrives at elevations over 1,100 m in protected tropical uplands. In some tropical areas it has been recorded to grow at 2,000 m. In Ethiopia the related species *Moringa stenopetala* is regularly found at altitudes up to 1,800 m.

The tree is reported to tolerate light frosts without significant damage. Even when a freeze kills a mature tree back to the roots, it usually quickly sends out new growth from the ground. A good overall temperature range is 20-30ºC. No upper limit has been reported. It is known that moringa can take up to 48ºC for limited amounts of time.

Moringa tree survives on all types of soils, including the heavier clays. However, it grows best on sandy sites and alluvial lands. The soil (especially the clay ones) must be well drained because the tree is sensitive to water-logging. It can be established in alkaline soils (up to pH 9) and acid ones (pH 4.5). In addition a rugged, resilient tree species of moringa tends to produce well in marginal growing conditions and is a reliable source of greens in seasons and locations where few other vegetables can produce much of anything.

### Good production practices

Cultivating of moringa for many farmers means growing trees. Moringa is a medium-sized tree that attains about 10 m in height. It has a straight trunk (10-30 cm thick) with bark that is whitish or gray, corky, with longitudinal cracks. It also has a tuberous taproot, whose presence helps to explain the species' tolerance to drought conditions. In India for example, where large-scale cultivation is practiced, the tree receives little professional horticultural attention and has not been subjected to formal comparative trials (Swaminathan Research Foundation, 2002). In Tanzania it is just a backyard tree and fence with hardly recognizable economic value with loose and difficult to harvest leaves and pods. This is envisaged to be one of the reasons which have led to the declining potential of moringa as a vegetable crop for Africa (Sutherland et al., 2001) (Figures 40 and 41).

Good agricultural practice to explore full economic use of moringa is possible. Evidence suggests that due to its rapid vegetative growth, regular pruning can maintain a compact form whose leaves are easily harvested, new leaves are produced in abundance or the plants can be managed to produce pods.

**Figure 40: Moringa tree planted at the backyard common in rural Africa**

**Figure 41: Picking moringa seed from over grown tree – Morogoro, Tanzania**

(Picture by Dr. J.P. Hella)

Moringa can be propagated through seed. No pre-treatment of seeds is required and seeds sprout in only a few days in well prepared seedbeds. However, this species is mostly (and most easily) propagated via cuttings. Even sections of branches as long as 0.5 m will root in moist soil, becoming tree-like in just a few months and producing fruit within a year. However, trees grown from cuttings tend to have short and spreading roots. Mulching and fertilizing improve production and quality of the leaves. Irrigation is seldom used but when used it tends to double or triple the yield of both leaves and seeds.

Recent studies by Reyes (2006) have shown that moringa trees can also be planted very close together as a field crop, at a spacing as close as 10-15 cm (Figures 42 and 43).

**Figure 42: Good planting practice for leaf yield maximization**

(Source: Reyes, 2006, in Nicaragua)

**Figure 43: Fully established moringa planted at close spacing**

(Source: Reyes, 2006, in Nicaragua)

Leaf harvesting in form of heavy pruning encourages lateral shoots and increased leaf production (Reyes, 2006). Heavy cutting can provide a continuing supply of wood, fodder, and other products. Both coppicing (continual cutting near the base) and pollarding (continual cutting higher up the trunk) are possible. One recommended system is to set the trees about a meter apart and trim them regularly like a hedge to provide successive crops of leaves (Figure 44).

The pods are usually taken directly from the trees individually by hand. The leaflets are easy to harvest by stripping them off between thumb and fore finger. As already noted, there is no leaf stalk to be removed and the leaves dry quickly and easily. The moringa plants then grow as a field crop, and can be harvested frequently. This technique produces a large amount of usable green matter from a relatively small amount of space.

**Figure 44: Good rotational harvesting practices to maximize yield**

(Source: Reyes, 2006, in Nicaragua)

Yield varies greatly. Moringa grown intensively with no irrigation and small amounts of fertilizer can yield leaves for harvest every 75 days – four crops in a year. One can get a total of 100 tons of green matter per hectare the first year, and 57 t/ha the second year. Planted under irrigation with larger amounts of fertilizer, harvesting can be done after every 35 days – nine crops per year – with a total yield of 650 to 700 tons of green matter per hectare. This yield has been consistent from the same plants for seven years (Foidl et al., 2001). An average tree grown under good conditions can, for instance, bear more than 1,000 pods a season and can supply leaves year round. If not for the height of the tree, the seeds can easily be picked.

By and large, diseases or pests seldom affect the moringa tree seriously. Close surveillance in Ethiopia shows a foot rot (*Diplodia*), a bark disease (*Indarbela*), and a defoliant are reportedly problematic. Also, caterpillars sometimes leave the tree leafless and termites sometimes tunnel into the trunk. Termites (*Macrotermes* spp.) can kill mature trees, especially during prolonged droughts. When planted in very wet conditions, it may suffer root rot. All in all, the entire crop is not greatly attacked by major pests or diseases which are common in most leafy vegetables hence do not need frequent application of toxic pesticides.

**Benefit cost analysis with GAPs**

According to FAO (2003), Good Agricultural Practices are a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economical, social and environmental sustainability. GAPs may be applied to a wide range of farming systems and at different scales. They are applied through sustainable agricultural methods, such as integrated pest management, integrated fertilizer management and conservation agriculture. They rely on four principles:

- Economically and efficiently produce sufficient (food security), safe (food safety) and nutritious food (food quality);
- Sustain and enhance natural resources;
- Maintain viable farming enterprises and contribute to sustainable livelihoods;
- Meet cultural and social demands of society.

Based on this definition, numbers of tangible and intangible benefits are discussed hereunder depicting contribution of the crop if good farming practices are followed.

***Tangible benefits***

The plant can provide various means to better life in the hot, harsh rural regions. Premature pods, grown-up pods, leaves, seeds, roots, seedlings, flowers and bark can be used directly or in combination of other food products for human consumption. Extracts such as oil, fuel and gums are also popular. Cooking oil equals in value to popular olive oil (Bakhru, 1995). Leaves can be eaten fresh, cooked, or stored as dried powder for many months without refrigeration, and without loss of nutritional value. It is more promising as a food source in the tropics because the tree is in full leaf at the end of the dry season when other foods are typically scarce.

Analyses of the leaf composition have revealed them to have significant quantities of vitamins A, B and C, calcium, iron and protein. Literature suggest that 25 grams daily of moringa leaf powder will give a child the following recommended daily allowances: protein 42%, calcium 125%, magnesium 61%, potassium 41%, iron 71%, vitamin A 272%, and vitamin C 22% (Creighton, 2001). These numbers are particularly astounding; considering this nutrition is available when other food sources may be scarce.

Scientific research confirms that these leaves are a powerhouse of nutritional value. Twenty five (25) grams of moringa leaves contain: seven times the vitamin C in oranges, four times the calcium in milk, four times the vitamin A in carrots, two times the protein in milk and three times the potassium in bananas. With its mother load of vitamins and minerals, moringa is possibly the planet’s most valuable undeveloped plant, at least in humanitarian terms (National Research Council, 2006).

Without considering several other benefits (tangible & intangible) such as medicinal, soil conservation, landscape beautification, plant for the honey bees, etc. which are associated with moringa cultivation, the Net Present Value (NPV) estimated for 15 years at 18% opportunity cost of capital from green leaves[19] alone is about Tshs 987,776100 (US$ 473,649.2) compared to Tshs 686,791,300 (US$ 473,649.2) which can be obtained from cultivating the popular Chinese cabbage (Tables 22 and 23). The Chinese cabbage has negligible social, medicinal and cultural value compared to moringa. Under irrigation and heavy doses of fertilizer, the NPV for moringa production can double or triple. It is important to note moringa realizes benefits at relatively lower cost than any other garden crop, thus it is an ideal crop for the poor (Figure 45).

***Intangible benefits***

The moringa tree has great medicinal use both preventative and as treatment. Although much of the evidence is anecdotal as there has been little actual scientific research done to support these claims, India's ancient tradition of ayurveda says the leaves of the moringa tree prevent 300 diseases. Field reports and ecological studies form part of a rich traditional medicine history claiming efficacy of leaf, seed, root, bark, and flowers against a variety of dermal and internal infections (Ramachandran et al., 1980; National Research Council, 2006).

[19] Assuming production is throughout the year and demand is stable

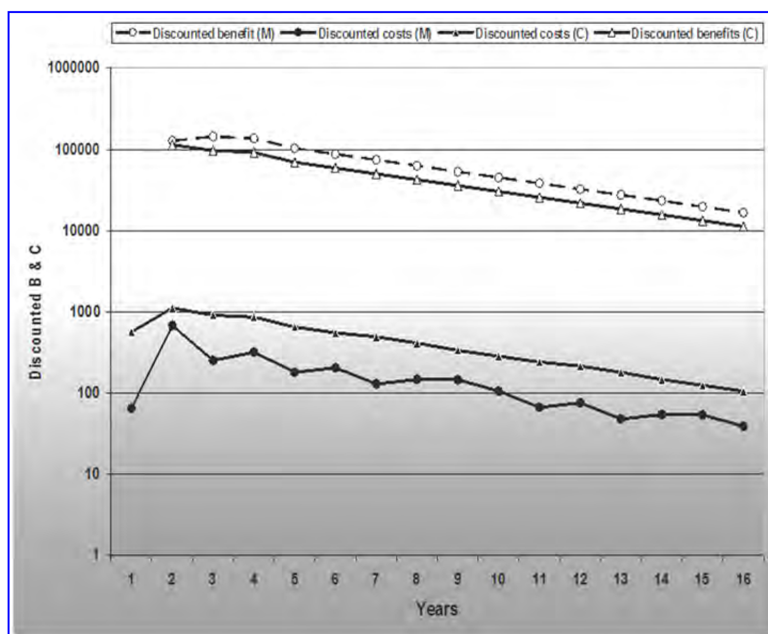


**Figure 45: Discounted benefits and costs based on moringa and Chinese cabbage production in Tanzania**

Another area of folklore which research supports is in cancer treatment. Moringa species have long been recognized by folk medicine practitioners as having value in the treatment of tumors. Studies examined certain compounds for their cancer preventive potential. Recently two of these compounds were shown to be potent inhibitors of activation of lymphoblastoid (Burkitt's lymphoma) cells.

After the oil is extracted from the pods, the seed-cake remaining contains the active components for removing turbidity (solid particles) from water. Because bacteria adhere to the solids, this seed-cake also effectively removes bacteria. In a study conducted at the Thyolo Water Treatment Works in Malawi, two researchers from the University of Leicester, England, have worked on substituting moringa seeds for Aluminum Sulphate (alum) to remove solids in water for drinking. Not only were the tests successful in removing as much solid material as alum, but the seeds used were "purchased from enthusiastic villagers in Malawi" (Foidl et al., 2001). Results suggested that not only is *Moringa oleifera* as effective as alum in removing suspended solids from turbid water but the fact that it can be produced locally, "using moringa rather than alum would save foreign exchange and generate farm and employment income." The potential for moringa to create a new market for a community is there, and studies and projects are taking place examining this potential. Use of this natural substance would also remove a source of aluminum contamination.

These have been considered as intangible benefits since they cannot be established directly. It can be noted that these benefits are based on cost saving – for example – for not buying industrial medicine or using alum water purifiers. In the analysis below these costs will not be considered as they can only be calculated based on shadow prices.

**Table 22: Cash flow estimated benefits and costs (Tshs) for moringa production**

(Tshs 1450 = 1US$)

| Field operation | Costs and benefits in Tshs/year | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Field establishment | 65 | - | - | - | - | - | - | - | - | - | - | - | - | - | -- | - |
| Primary land preparation | - | 50 | - | - | - | - | - | - | - | - | - | - | - | - | -- | - |
| Secondary land preparation | - | 30 | - | - | - | - | - | - | - | - | - | - | - | - | -- | - |
| Planting/ transplanting | - | 150 | - | - | - | - | - | - | - | - | - | - | - | - | -- | - |
| Seed | - | 200 | - | - | - | - | - | - | 200 | - | - | - | - | - | 200 | - |
| Fertilizer application | - | 120 | | 120 | | 120 | | 120 | | 120 | | 120 | | 120 | | 120 |
| Weeding | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Harvesting/ prunning | - | 150 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Total cost | 565 | 1315 | 1265 | 1265 | 1265 | 1265 | 1330 | 1315 | 1265 | 1265 | 1265 | 1330 | 1315 | 1265 | 1265 | 1265 |
| Total benefit | 0 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 | 134400 |
| Net benefit | -565 | 133085 | 133135 | 133135 | 133135 | 133135 | 133070 | 133085 | 133135 | 133135 | 133135 | 133070 | 133085 | 133135 | 133135 | 133135 |
| Discount factor (18%) | 1 | 0.8475 | 0.7182 | 0.6806 | 0.5158 | 0.4371 | 0.3704 | 0.3139 | 0.266 | 0.2255 | 0.1911 | 0.1619 | 0.1372 | 0.1163 | 0.0986 | 0.0835 |
| Discounted NPV | -565 | 112790 | 95618 | 90612 | 68671 | 58193 | 49289 | 41775 | 35414 | 30022 | 25442 | 21544 | 18259 | 15484 | 13127 | 11117 |
| **Net Present Value** | | | | | | | | | | | | | | | | **987,776.1** |

**Table 23: Cash flow estimated benefits and costs (Tshs) for Chinese cabbage production**

(Tshs 1450 = 1US$)

| Field operation | Costs and benefits in Tshs/year | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Field establishment | 65 | - | - | - | - | - | 65 | - | - | - | - | 65 | - | - | - | - |
| Primary land preparation | - | 50 | - | - | - | - | - | 50 | - | - | - | - | 50 | - | - | - |
| Secondary land preparation | - | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Nursery planting | - | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Transplanting | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Seed | - | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Fertilizer | - | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Fertilizer application | - | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Pest/disease control | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| Irrigation | 500 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Weeding | - | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| Harvesting | - | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| Total benefit | 0 | 150000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 | 200000 |
| D-factor (15%) | 1 | 0.8475 | 0.7182 | 0.6806 | 0.5158 | 0.4371 | 0.3704 | 0.3139 | 0.266 | 0.2255 | 0.1911 | 0.1619 | 0.1372 | 0.1163 | 0.0986 | 0.0835 |
| Discounted benefit | 0 | 127125 | 143640 | 136120 | 103160 | 87420 | 74080 | 62780 | 53200 | 45100 | 38220 | 32380 | 27440 | 23260 | 19720 | 16700 |
| Discounted costs | 65 | 678 | 251.37 | 319.88 | 180.53 | 205.44 | 129.64 | 147.5 | 146.3 | 105.99 | 66.885 | 76.093 | 48.02 | 54.661 | 54.23 | 39.245 |
| Net Present Benefit | (65) | 126447 | 143389 | 135800 | 102979 | 87215 | 73950 | 62632.5 | 53054 | 44994 | 38153 | 32304 | 27392 | 23205.3 | 19666 | 16661 |
| **Net Present Value** | | | | | | | | | | | | | | | | **686,791.3** |

## POTENTIAL FOR REVIVAL MORINGA PRODUCTION THROUGH DEMAND ACTIVATION AND GAP REQUIREMENTS

With increased evidence of climate change and associated environmental hazards, food insecurity and ill health problems, growing moringa in Tanzania offers a rare opportunity stemming from social, economic and cultural needs which addresses four pillars of GAP i.e. economically and efficiently produce sufficient (food security), safe (food safety) and nutritious food (food quality), sustain and enhance natural resources, maintain viable farming enterprises and contribute to sustainable livelihoods and meet cultural and social demands of society because of the following reasons:

**Fighting Hunger** – an ability to provide so many different foods makes this tree potentially valuable for the needy and destitute. It produces high yields at little cost or effort from the growers.

**Malnutrition** – the pods and leaves are among the most nutritious foods to be found in the plant kingdom. In eastern Africa the leaves appear at the end of the dry season, when there are few other sources of leafy green vegetables. Several programs already promote production of moringa leaf powder for use in sauces or as a general food additive.

**Rural Poverty** – potentially there is profit in moringa. First, this is a fast-growing, high-yielding oilseed. Second, the trunk is gaining importance as a raw material for papermaking. And third, pods can be produced for the fresh market or for processing.

**Public Health** – with its mother load of vitamins and minerals, moringa is virtually a nutritional supplement for farms or villages. Exceptional levels of iron and calcium make it particularly valuable for young and old women. Adding to its public-health benefits is that its seeds can help purify water. There are also indications that seed extracts are useful treatments against skin complaints.

**Deforestation** – this species is not a foresters’ tree but its ability to thrive in wastelands and provide rapid shade cover could make it the choice for many tree-planting projects. Likely, too, it is a good nurse crop for slower-growing species that eventually will dominate the site.

**Visual blight** – moringa is an excellent candidate for fast-track beautification of streets, slums, and squatter settlements. The average specimen looks like an arborist’s nightmare, but a little care can endow it a pleasing rounded appearance. Interestingly, it might help to de-uglify the mega-cities that are projected to dominate the future of the tropics, and make them more livable.

It should be noted that although moringa has many potential products for the market, there is one constraint to widespread production that is common to all of them, that is they are all considered to be ‘new’ products. As such, the development of any new product brings with it a host of interlinked constraints. According to Sutherland et al. (2001) and GAP requirement (FAO, 2003) they include:

*Financial* – this is perhaps one of the most significant constraints. The development of a new product on any scale can require a significant financial investment. Unless this development is being undertaken by an existing company/organization/government, it is not an easy matter to obtain funding for a start-up company to produce a product that has, initially, no guarantee of a market. Thus there is a need to formulate a set of generic practices and indicators from which guidelines for good agricultural practices for on-farm production and post-production systems can be developed collaboratively by the public sector, private sectors and civil society.

*Research and development* – this is a very broad yet significant constraint. These are just a couple of many examples where there exists a gap between 'scientific' and 'practical' research with the result that in order for a product to be developed on a commercial scale a significant amount of research and development has to be undertaken prior to that product reaching the market place. This does not mean that the most effective and optimized process/cultivation practice (i.e. GAP), for example, has to be found prior to producing and selling a product. Meaning that marketing research has to be addressed to commercialize the moringa products so as to stimulate GAP initiatives.

*Market awareness* – the introduction of a new product within existing markets is never an easy job and requires an extensive knowledge of the market to which the product is being brought. Given that all the potential products for moringa would be placed in already highly competitive markets, this is perhaps one of the most significant constraints to commercial development. GAPs through value chain, specialist products and production cluster formations are needed.

*Regulatory approval* – in general it is not possible today to produce a new product on a commercial scale, bottle it, stick a label on it and offer it for sale to the general public. Almost all countries have regulatory authorities in place to ensure the quality and safety of products that are being offered for sale. Spear-heading GAPs for moringa production need to be addressed by engaging discussion with governments on their strategies, priorities and instruments to move towards sustainable agriculture and rural development practices.

Although there are many other constraints to commercialization that could be addressed, all in all, moringa as vegetable crop is the potential crop for Tanzania within the dimensions of increased malnutrition, health and climate problems more than any other time of its historical past. Thus there is a need to develop GAP guidelines for on-farm production and post-production systems, involving the participation of farmers, and bringing together scientific and technical expertise and civil society.

## CONCLUSION AND RECOMMENDATIONS

Traditional vegetables can contribute substantially to household food security in Tanzania and many countries in sub-Saharan Africa. Thanks to substantial research effort and promotion in subsequent years, a number of vegetables indigenous to Africa are currently produced on a commercial scale. As presented in this paper, moringa is the right crop for the current time both from social, economic and environmental point of view. If our people are taught to adopt good production practices, lives of many poor, especially women and children, would be saved. Researchers, policy makers, and NGOs must advocate the importance of moringa as a nutritionally balanced food, as a source of income, medicine, fodder, water purification, soil & water conservation, particularly for the resource poor families. This is an opportune time to develop GAP guidelines for on-farm production and post-production systems for moringa. The process should involve the participation of farmers, and bringing together scientific and technical expertise, and civil society. Thus the following recommendations are put across:

- Conduct more evidence based research to inform the society about the agronomy, nutritive value, medicinal effects, and as livestock feed is needed. Thus we call for increased efforts to bring moringa into cultivation through market promotion and advanced research on good production practices affordable by small scale farmers within their local settings.
- Maintain a common information base on promising integrated moringa production techniques for major agro-ecological zones, by collecting, analyzing and disseminating information (data, summary reports) on good practices in relevant geographical contexts.

- Pilot projects to verify the conditions of application of selected promising techniques in systems that have potential for sustainable production increases.
- Decision-support systems promoted in countries based on knowledge accumulated through the above activities.

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# Good Agricultural Practices for the Production of Underutilized Vegetables in Sub-Saharan Africa: Case of Jute Mallow (*Corchorus* sp.) in Côte D'Ivoire

**Mako François De Paul N'Gbesso[1]*, Lassina Fondio[1], Jean Claude N'Zi[1], Adolphe Mahyao[1], Edith Adouko Agbo[2] and Hortense Andé Djidji[1]**

*[1]CNRA/Vegetables and Proteagineous Crops Research Programme, 01 BP 1740 Abidjan 01, Côte d'Ivoire*
*[2]Université d'Abobo-Adjamé, UFR Sciences et Technologie des Aliment, 02 BP 801 Abidjan 02, Côte d'Ivoire*
**Corresponding author (mako_ngbesso@yahoo.fr)*

**Abstract**

A diagnostic survey of the leafy vegetable sector was conducted in the cities of Yamoussoukro and Abidjan involving producers, traders and consumers. Several accessions of leafy vegetable were collected but only two accessions of jute mallow were found. These accessions have been characterized on station. Concerning nursery management, farmers broadcast the seed on the beds usually with organic manure as fertilizer. Seedlings are transplanted about one month after sowing of seeds in nurseries. Like the other leafy vegetable species, there are no improved varieties of jute mallow cultivated in Côte d'Ivoire. The plant material used comes from the seed panicles harvested by farmers themselves from their own farms. Farmers systematically apply fertilizers in leafy vegetable production. The main fertilizers used are NPK, urea and organic matter. Currently, they use a combination of these three types of fertilizers. In the case of jute mallow, monocropping was the system most commonly encountered. Planting is done at high density. In case of mixed cropping, the main vegetables frequently associated with jute mallow are tomato, lettuce, onion, okra, cabbage, etc. The cultivation of leafy vegetables is generally associated with the rainy season. However, during the dry season, farmers frequently irrigate the plants with water from wells that they dig in the beds of rivers or in the lowlands. To protect their crops against insects and diseases, 80 to 90% of producers use pesticides. During the investigation it was observed that more than two dozen chemicals are applied to crops by producers of Abidjan and Yamoussoukro. Harvesting technique depends on the production system (mono or mixed cropping). Generally, for the monocropping system, farmers harvest by uprooting the whole plant about 30-40 days after transplantation. In Côte d'Ivoire, jute mallow is consumed in local recipes, generally in sauce whose preparation varies with ethnic group. The urban areas' gardens are the main source of leafy vegetable in the major local markets. The productions from rural and peri-urban areas are marginal sources and they are destined for the central market of the town. The availability of traditional leafy vegetables varies by season and by market. This seasonal variation in supply affects the prices of leafy vegetables. Work on genetic characterization, varietal evaluation and fertilization performed at jute mallow, has generally improved the productivity of this traditional leafy vegetable to the continuous availability in the markets.

**Keywords:** good agricultural practices, jute mallow, Côte d'Ivoire

## INTRODUCTION

All the traditional vegetables contribute to human well-being. They are affordable and are found in market of towns and villages (Agbo, 2007). African leafy vegetables are a particularly important source of protein, vitamins, minerals and fiber essential in the diet of urban and peri-urban populations of major cities in Africa. These products are also a source of additional and substantial income for producers. In general, very little information exists on these traditional leafy vegetables cultivated in Côte d'Ivoire. Recent prospecting and collection carried out on these vegetables in Côte d'Ivoire showed that jute mallow (Figure 46) or *Corchorus* sp. or kplala (local name) occupies a prominent place in terms of consumption and amount of leaves sold in local markets. This survey also revealed that these traditional leafy vegetables are diversified. In farmers fields, cultural practices vary from one farmer to another. At research stations, actions have been undertaken to define good agricultural practices for these African leafy vegetables to boost their productivity and quality in Côte d'Ivoire.

**Figure 46: Jute mallow plant (*Corchorus olitorius)***

## CULTIVAR SELECTION, PLANTING MATERIAL AND NURSERY MANAGEMENT

Farmers use various ways to obtain seeds of a leafy vegetable. For jute mallow, most farmers produce their own seed. They retain some for themselves for the next season and sell the surplus to other producers of leafy vegetables. An inventory of local cultivars of jute mallow in urban and peri-urban gardening carried out in Abidjan and Yamoussoukro enabled us to collect several accessions of leafy vegetable species. But only two (2) accessions of jute mallow were collected (Table 24). These accessions correspond to two species (*Corchorius tridens* and *Corchorius Olitorius*) commonly referred to as kplala (vernacular name) belonging to the *Tiliaceae* family. Like other leafy vegetable species, there are no improved varieties of jute mallow cultivated in Côte d'Ivoire. The plant material used comes from the seed of panicles harvested by farmers from their own farms. These seeds are obtained through several processes such as cutting of mature pods drying, shelling and winnowing. There is no formal seed system and there are no structures to assist farmers in quality seed production. In these conditions, quality of seeds produced is often poor in terms of purity and viability.

**Table 24: Accessions of jute mallow characterized**

(Source: N'Zi, 2008)

| Number of accessions | Accessions | Species |
|---|---|---|
| 02 | AMPT04<br>YAK02 | *Corchorius tridens*<br>*Corchorius olitorius* |

Concerning nursery management, farmers spread the seed directly on the beds usually with organic manure as fertilizer. However, there are no disease and pest management techniques used for seedling protection in the nursery. After the sowing, growers cover the beds with palm leaves or other leaves which can protect the seedling against rain or sunshine (Figure 47). Seedlings are transplanted about one month after seed sowing in nurseries.

**Figure 47: Nursery bed covered with palm leaves after seeds sowing**

To ensure compliance with good agricultural practices in nursery management, CNRA recommends that farmers till the soil properly before preparing raised beds and apply 20 g/m² of NPK (10-18-18) or 2 kg/m² of organic manure made of poultry droppings. This organic manure must be well-composted for about 2 to 3 months before utilization. Seeds are sown on the beds in lines and are separated from each other by a distance of about 10 cm. Beds are covered with palm leaves for 15 days after sowing, and must be regularly watered. Seedlings are transplanted after 25-30 days after seed sowing (Figure 48) at true leaf stage (15 cm of height).

**Figure 48: Seedlings transplanted after 25-30 days**

## GERMPLASM AND DIVERSITY

Accessions collected are being characterized at the research station (Tables 25 and 26). For this characterization the IPGRI descriptor has been used as advised by Grubben and van Sloten (1981). Forty one descriptive variables (21 qualitative and 20 quantitative) were used in the characterization. It appears from these studies that the jute mallow plants are woody, erect, thornless with a mean height of 70 cm. Germination of seeds sown in the nursery takes about 4 days. Plant came into bloom 60 days after sowing in the nursery bed. The flowers are small and yellow. The leaves are bright green, alternate and tooth-edged. The length of the blade varies from 3.5 to 5.8 cm. The width of the blade oscillates between 2.8 and 4 cm. The leaf shape is lanceolate. The tip and base of the blade is sharp. The stem is greenish-brown and about 1.8 cm wide and 70 cm long. The green stalk has a length of 4 cm. The fruit pods are elongated and threadlike 4 to 7 cm. The seeds are brown and flattened with 1.2 mm of diameter.

## BREEDING OF JUTE MALLOW

CNRA has initiated a breeding program for jute mallow. A breeding program will be initiated after collection missions of jute mallow accessions and germplasm characterization have been concluded. Development of late flowering varieties that are resistant to major fungal (e.g. damping off), and virus (e.g. mosaic) diseases, as well as to insect pests (e.g. flea beetle) would figure among the major research priorities of this breeding program.

## SOIL FERTILITY AND PLANT NUTRITION

Farmers systematically apply fertilizers in the production of leafy vegetables. The main fertilizers used are NPK, urea and organic matter. Farmers currently use combinations of these three types of fertilizers. To develop a technical protocol for jute mallow production, a trial was conducted in 2008 at Anguédédou research station on the determination of optimal fertilizer doses. The organic manure consisted of well-decomposed poultry manure. The mineral fertilizer was NPK (10-18-18). It was found that fertilizer doses had no significant effect on the number of branches produced by jute mallow. Leaf production varied between 5.7 and 8.7 t/ha depending on the dose of fertilizer. The dose of mineral fertilizers of 400 kg/ha of NPK (10-18-18) gave the highest yield of 8.7 t/ha (Fondio et al., 2009). With this fertilizer dose, the profit obtained is 226 F CFA/m² (US$ 0.45) according to Mahyao (2007).

## CROPPING SYSTEMS/ORGANIC PRODUCTION

Investigation conducted in peri-urban areas of Abidjan and Yamoussoukro revealed that leafy vegetables are generally grown in mixed or in monocropping systems. Production is year-round in urban areas and only during the rainy season in rural and peri-urban areas. About 70 to 73% of the producers cultivate leafy vegetables in mixed cropping. In the case of jute mallow, monocropping was frequently encountered (Figure 49). The planting is done at high density. In case of mixed cropping, the main vegetable crops frequently associated with jute mallow are tomato, lettuce, onion, okra, cabbage, etc. (Table 27). In these conditions, the main crop is planted centrally in the field while other vegetables are planted on the borders.

To develop a technical protocol for jute mallow planting, trials were carried out at the research station of Anguédédou in Abidjan, in order to establish the optimum transplanting density. Jute mallow leaf yield varied significantly between 2.1 and 3.8 t/ha depending on planting densities evaluated. Moreover, these yields are not significantly higher than those of the recommended standard density of 100.000 plants/ha (20 x 50 cm). The optimum transplanting density of jute mallow was established to be 39 plants/m² (Mahyao, 2007).

**Table 25: Quantitative characteristics of two accessions of jute mallow evaluated on station**

| Accession | Days to germination (days) | Days to flowering (days) | Plant height (cm) | Stalk width (cm) | Stem width (cm) | Blade length (cm) | Blade width (cm) | Leaf number | Fruit length (cm) | Seed length (mm) | Seed width (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AMPT04 | 4 | 60 | 69 | 1,8 | 4 | 3,5 | 2,8 | 51 | 7 | 1,2 | 1,1 |
| YAK02 | 4 | 60 | 71 | 1,8 | 4 | 5,8 | 4 | 48 | 4 | 1,2 | 1,2 |
| Average | 4 | 60 | 70 | 1,8 | 4 | 4,7 | 3,4 | 50 | 5,5 | 1,2 | 1,15 |

**Table 26: Jute mallow species produced in urban and peri-urban areas in Abidjan andYamoussoukro, in Côte d'Ivoire**

(Source : N'Zi, 2008)

| Common name | Local name | Species | Botanic familly | Edible parts | Utilisation |
|---|---|---|---|---|---|
| Jute mallow (Tège) | Kplala | *Corchorius tridens* and *Corchorius olitorius* | *Tiliaceae* | leaves | Sauce |

**Table 27: Major crops with which leafy vegetables are associated**

(Source: Fondio et al., 2007)

| Species | (%) of farmers in Abidjan<br>*(Number of farmers investigated: 304)* | (%) of farmers in Yamoussoukro<br>*(Number of farmers investigated: 255)* |
|---|---|---|
| Tomato | 0 | 38 |
| Lettuce | 28 | 23 |
| Okra | 26 | 0 |
| Chive | 10 | 27 |
| Cabbage | 0 | 13 |
| Maize | 4 | 4 |
| Cassava | 0 | 3 |
| Groundnut | 0 | 2 |

**Figure 49: Monocropping of jute mallow in M'pouto located in the urban zone of Abidjan**

## IRRIGATION AND WATER MANAGEMENT AND INTEGRATED DISEASE AND PEST MANAGEMENT

The cultivation of leafy vegetables is generally associated with the rainy season. However, during the dry season, farmers irrigate plants frequently with water from wells that they dig in the beds of rivers or in low lying areas with high water tables. CNRA advises farmers to irrigate plants with clean water during the dry season and to supplement rainfall during the wet season. Unfortunately, sometimes in urban plots, waste water discharged into drains is used fraudulently for plant watering. Specific studies are necessary to determine exactly the water needs of jute mallow plants at all developmental stages.

To protect their crops against insects and diseases, 80 to 90% of producers use pesticides. During the investigation, researchers identified more than two dozen chemicals used by producers of Abidjan and Yamoussoukro. In case of intercropping, the chemicals used are not specific for leafy vegetables. These products are first applied for the main crops. Sometimes they are not approved and they are sold illegally. Consequently, there are enormous risks that the leaves contain residues of chemicals that could pose a threat to farmer and consumer health (Fondio et al., 2007).

## POST-HARVEST MANAGEMENT

### Harvesting

Harvesting technique depends on the production system (mono or mixed cropping). Generally, for the monocropping system, farmers harvest by uprooting the whole plant about 30-40 days after transplantation. In the mixed cropping system, they cut stems and leaves weekly about 15 cm from the ground. This technique allows new side shoots to develop. At the research station, jute mallow is harvested by cutting frequently.

### Processing/recipes

In Côte d'Ivoire, jute mallow is consumed in local recipes generally in a sauce whose processing depends on ethnic groups (Figure 50).

1-Ingredients

2-Leaves flood looted

3-Cooking

4-Jute mallow sauce

**Figure 50: Steps of preparation of jute mallow sauce mixed with palm oil in the western part of Côte d'Ivoire**

### Packaging

Vegetables are highly perishable products. A suitable packaging is necessary to facilitate the conservation of product quality and transportation to the markets. Unfortunately, appropriate packaging is often non-existent in vegetable market in Côte d'Ivoire. Indeed, producers and traders wrap their products in bags to transport them from the field to the markets. In these markets leaves are sold generally in bundles. In the context of good agricultural practices and in order to promote traditional vegetables for poverty alleviation in Africa, it is necessary to develop and ensure widespread adoption of appropriate packaging for these traditional vegetables. This will greatly facilitate transportation to the market, enhance the quality products on sale in the market, increase availability of high quality jute mallow and sale increase farmers' income in Côte d'Ivoire.

### Storage/preservation

Generally, farmers harvest jute mallow a day before or the same day of the sale. Leaves harvested the day prior to sales are stocked in open air in heaps that are sprinkled with water to preserve leaf freshness. There is no special preservation method used for jute mallow leaves in Côte d'Ivoire. Producers and sellers struggle to sell all their produce to avoid waste of any surpluses that may not be bought. However, it would be important to develop storage/preservation facilities for jute mallow leaves in order to address the problem of shortage or to enable a regulation of the market in periods of abundance.

### Marketing systems and linking farmers to markets

A study of the characteristics of the market revealed that local markets, with 73% of quantities sold, dominate the central markets (27%) in the marketing of leafy vegetables. Based on the quantities sold, traditional leafy vegetables can be classified into three groups: the first group with 81% includes the main leafy vegetables (amaranth, spinach, potato leaves …) that are heavily marketed with 7% for jute mallow. The second group (13%) includes leafy vegetables sold moderately (like nightshade, spider plant, cowpea leaves…). The third group with 6% is poorly marketed (eggplant, taro and onion leaves…). The analysis of seasonality in supply and prices revealed that at the level of major leafy vegetables, price fluctuations are less important for leaves sold in large quantities. Overall, it appears that local

markets generally dominate the marketing of major traditional leafy vegetables in Yamoussoukro and Abidjan.

The gardens of urban areas are the main sources of leafy vegetable for the local markets. The productions from rural and peri-urban areas are marginal sources and they are destined for the central markets of the town. The availability of traditional leafy vegetables varies by season and by market (Table 28). This seasonal variation in supply affects the prices of leafy vegetables (Mahyao, 2007).

**Table 28: Percentage of farmers cultivating jute mallow for local and central markets in Abidjan and Yamoussoukro**

| | **% of farmers producing jute mallow for Abidjan markets** *(Number of farmers investigated: 605)* | **% of farmers producing jute mallow for Yamoussoukro markets** *(Number of farmers investigated: 389)* |
|---|---|---|
| Jute mallow | 57 | 12 |

## CONCLUSION AND PERSPECTIVES

For production, the profitability analysis of cultivation techniques of jute mallow has been presented from the results of tests and fertilization seeding. The optimal techniques of production have been identified. Despite of these available results, producers of jute mallow are facing many problems. These marketing problems are: lack of marketing information and supply channels (e.g. consumers are not aware of nutritional values and economic opportunities of a leafy vegetable such as jute mallow, etc.), lack of access to resources (no access to credit, production with rudimentary tools, high input costs, etc.), bad quality of seeds, lack of a package of production technologies and poor access to information (lack of training of farmers and extension workers in modern culture GAP-compliant jute mallow production; lack of technology transfer to farmers, etc.). Based on the diagnosis survey, the following were identified as priorities issues to be addressed in order to ensure GAP compliance and increase the productivity of jute mallow in Côte d'Ivoire. These include the need to:

- Enhance the collection of jute mallow germplasm through surveys in other localities as a prerequisite to initiating a program of breeding;
- Develop a better method of use of fertilizers and pesticides;
- Promote the economic and nutritional value of leafy vegetables in general and jute mallow in particular in order to increase the consumption of these traditional foods;
- Transfer new technologies developed to farmers in rural areas.

So, analysis and study of social conditions of acceptance all of these production techniques by the producers will be considered in collaboration with researchers and agronomists. Consumption level, the additional costs of processing selected on the basis of nutritional quality and commercial importance of jute mallow should be evaluated. The collection should be enriched by more accessions for the establishment of a real breeding program.

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# Good Agricultural Practices for Production of Okra in Sub-Saharan Africa

**O.J. Ariyo[1] and F.O. Olasantan[2]**

[1]*Department of Plant Breeding and Seed Technology, University of Agriculture, Abeokuta, Nigeria*
[2]*Department of Horticulture, University of Agriculture, Abeokuta, Nigeria*

**Abstract**

Good agricultural practice is the total sum of all processes in farm operations that optimise the natural and environmental potentials of a crop. The genetic potential of okra determines its usefulness as a nutritional crop, its adaptation and cropping pattern. It leads to prodution of adequate food and cash crops and promotes responsible use of agricultural inputs such as fertilizer, good quality seed, cropping systems and agro-chemicals in order to ensure sufficient and affordable food production.

For optimum pod and seed production, a good agricultural practice is important in bringing out the maximum effects of quality seeds, crop genetic resources, cultural practices such as clearing, planting, weeding, pest and disease control, timely harvesting, good packaging, processing, storage and preservation methods.

## INTRODUCTION

Okra, *Abelmoschus* spp., is an often self-pollinated annual belonging to the family *Malvaceae.* The exact origin of cultivated okra is controversial (de Candolle, 1886) but Zeven and Zhukovsky (1975) believed it originated in the Hindustani centre of origin which likely corresponds to India. However, Franklin and Ruberte (1978) and Siemonsma (1981, 1982) suggested a west African origin until the two okra types were classified as two separate species on account of chromosome numbers and other morphological characteristics (Table 29; Siemonsma, 1981, 1982; Ariyo, 1985), although it is being argued (Joshi and Hardas, 1976) that west African okra might be an amphidiploid of *A. esculentus* and *A. manihot.*

**Table 29: Some characteristic features of west African okra and *Abelmoschus esculentus***

(Source: Ariyo, 1985)

| Character | West African Okra | *Abelmoschus esculentus* |
|---|---|---|
| Pod yield/plant (g) | 295 | 114 |
| Final plant height (cm) | 175 | 86.5 |
| Stem diameter (cm) | 6 | 2.6 |
| Number of branches/plant | 30 | 5.0 |
| Size of epicalyx segment | Large | Small |
| Persistence of epicalyx segment | Persistent | Less-persistent |
| Photoperiodism | Sensitive | Non-sensitive |
| Number of pods/plant | 13 | 6.0 |
| Length of branches (cm) | 28 | 12.5 |
| Chromosome number | n=194 | n=130 |

The tender pods and leaves are often used as vegetables. While the pods are either boiled or sliced and fried, the leaves are used as leaf vegetables. A 100-gram serving of okra will supply about half the recommended daily allowance (RDA) of vitamin C for an adult male. The contents of calcium, vitamin A, thiamine and riboflavin are each about 10% of the RDA. Phosphorus, iron and niacin contents are considerable. It has been reported that okra is an excellent source of iodine which is useful for the control of simple goitre (Purewal, 1944). The nutrient content of okra fruit indicates that it is very rich in protein, calcium, phosphorus, magnesium, potassium, iron, copper and sodium (Table 30; Ariyo, 1985).

**Table 30: Crude protein (CP) and mineral content, on dry matter basis, of eight okra lines**

(Source: Ariyo, 1985)

| Line | CP (%) | Ca (%) | P (%) | Mg (%) | K (%) | Fe (ppm) | Cu (ppm) | Na (ppm) |
|---|---|---|---|---|---|---|---|---|
| UI 1-1 | 17.4 | 0.5 | 0.5 | 0.5 | 3.0 | 82.7 | 5.0 | 305.0 |
| UI 4-30 | 14.0 | 0.9 | 0.5 | 0.5 | 3.0 | 58.3 | 20.0 | 195.0 |
| UI 22-77 | 15.9 | 0.9 | 0.5 | 0.5 | 2.9 | 48.3 | 15.0 | 205.0 |
| UI 53-139 | 14.8 | 0.6 | 0.5 | 0.5 | 2.8 | 75.0 | 5.0 | 165.0 |
| UI 72-11 | 15.2 | 0.8 | 0.5 | 0.5 | 2.9 | 65.0 | 20.0 | 295.0 |
| UI 104 | 16.5 | 0.7 | 0.5 | 0.4 | 3.0 | 60.0 | 10.0 | 260.0 |
| UI 204-2-3 | 15.2 | 0.7 | 0.5 | 0.5 | 3.0 | 68.3 | 10.0 | 191.7 |
| UI C-6-2 | 15.2 | 1.0 | 0.5 | 0.5 | 3.1 | 78.3 | 15.0 | 277.5 |

The potential of the seeds as a new source of protein has been emphasised (Karakoltsides and Constantinides, 1975). The protein content of the seed is 20-60%, making the seed meal valuable as a feed. The oil content of okra seeds ranges between 14 and 19% and consists of a significant proportion of the essential fatty acid, linoleic acid (Arulrajah and Ormrod, 1973).

Whether okra will become a major source of oil and protein depends largely on breeding and selection as most tropical genotypes currently under cultivation are unselected and are characterised by relatively low yields and poor fruit and seed quality.

The objective of this paper is therefore to highlight the genetic potential of okra and how various management practices can be exploited to optimise the agricultural inputs for maximum productivity.

## CULTIVAR SELECTION

Cultivar selection puts premium on genotypes that are adapted to the environment, high yielding, disease/pest resistant and upon all acceptable to consumers. A cultivar with these attributes will maximise outputs and bring high returns on investment.

Selection is the oldest method of crop improvement known to man. As a result of continuous selfing the heterozygosity created by hybridisation gradually turns homozygous. Hybridisation leads to gene recombination which is the raw material for further improvement. Continous selfing for 4 to 5 cycles produces homozygous individuals which could be evaluated as lines. Mass selection is the simplest and fastest method of improvement. The basic idea of the technique is to eliminate undesirable types from the population. Usually, it is used to purify the variety by eliminating off-types. This involves selecting individually a large number of plants with desirable characteristics and bulking them to evolve a new variety. The selection objectives are to a large extent similar in most places. However, the principal interests are: high yield, adaptation, stability, tolerance to pests and diseases, mucilaginous and other organoleptic properties. In India, preference is given to long slender fruits as

examplified by ‘Pusa Sawani’. Nearly every cosumer prefers dark green glabrous/soft-haired fruits. While Nigerians prefer mucilaginous fruits, the Indians want it less mucous.

In selecting cultivars of okra, attention has always been paid to the dominant cropping system as okra is rarely grown as a sole crop. The accepted crop cultivar is the type that would allow other crops to grow with it. Therefore, attention has always been given to tall plants with highly lobed leaves to permit light peneration to the lower crops. Farmers prefer cultivars with prolonged flowering period to make fruits available for a fairly long time. This is why *A. caillei* is preferred by the local farmers because of the duration of fruit bearing. The bulk of studies so far conducted has been on *A. esculentus* with limited work on *A. caillei*.

The available planting materials in many countries are mainly introductions and land races which are cultivated under various cropping systems. In Nigeria, we have such introductions as ‘Pusa Sawani’ from India and accession such as UI 72-11 from Japan, UI 72-104 from Turkey and NHAe 626 from Zambia. The improvement of okra has followed techiniques normally used for autogamous species after hybridisation. Rarely has $F_1$ vigour been exploited in okra production in Nigeria but there is evidence that it has been used in some west African countries. The segregating populations are advanced through various selection techniques such as pedigree, line selection, backcross method, single seed descent method and bulk method. The selection techinique to employ depends upon the objectives of the breeder and the available materials, but the pedigree method is the most frequently used.

Cultivar selection puts premium on genotypes that are adapted to the environment, high yielding, disease/pest resistant and upon all acceptable to the consumers. A cultivar with these attributes will maximise outputs and bring high returns on investment which is the hallmark of good agricultural practice.

## PLANTING MATERIALS AND NURSERY

Okra is a crop propagated by seed for its fresh fruits and leaves in the tropical and sub-tropical world. Its seeds are relatively large and heavy with an average weight of 4.0-6.5 g/100 seeds and the color varies from light green to grey (Ariyo, 1985).

Planting seeds shortly after harvest often leads to dormancy. Okra seeds therefore need an after-ripening period to produce uniform field establishment. The hard coat of the seed could also interfere with water uptake thereby impairing germination. Several methods are, however, available to enhance seed germination in okra including scarification mechanically or with sulphuric acid and pre-soaking.

Okra seeds to be used for sowing normally should have 12-13% moisture content. A critical level of moisture required for germination varies with cultivar. In Nigeria, okra seed is usually sown by dibbling in the available space on the farm.

The bulk of materials used for planting in west Africa comes from local varieties/landraces transferred from farmer to farmer. However, seed companies market some foreign varieties and local improved varieties. The popular cultivars from the companies include ‘Pusa Sawani’, ‘Clemson Spineless’, UI 104, and NHAe 47-4; the bulk of the planting materials still comes from local cultivars.

## GERMPLASM AND DIVERSITY

Genetic conservation will have little meaning without the prospect of utilization in plant breeding or other branches of research. Utilization in plant breeding depends on the evaluation of relevant characteristics as an essential prerequisite, the availability of the resulting information in a readily available crop information system, as well as stocks from a

well organized network of collections. A systematic descriptive documentation of collections is the key to their utilization. It is not an overstatement that the relatively limited use which has been made of large existing collections is mainly attributable to the deficiencies of the existing documentation which may restrict the usefulness of a collection even within the institution keeping it, and much more so to the other potential users (Frankel, 1976).

The genus *Abelmoschus* included in the *Malvaceae* family by the German botanist Friedrich Medikus at the end of the 18$^{th}$ century had been previously classified in the genus *Hibiscus.* Hochreutiner (1924) mentioned 14 species from which two (*A. moschatus* and *A.* m*anihot*) were excessively complex because they were composed of different botanical taxa.

Bioversity International (formerly IBPGR and IPCRT) and ORSTOM contributed to the increase in the genetic resources of okra as well as the improved understanding of the genus *Abelmoschus*. Commercial varieties of okra were introduced into India in the 1940s. Such varieties included Clemson Spineless, Perkins Long Green and Smooth Long. Overtime, introductions have been made from countries such as United States, Brazil, Turkey, Russia, Ghana, India among others. Dhankhar et al. (2005) reported that 148 exotic germplasms, 150 accessions from Brazil and 177 entries from the World Okra Core collections were stored by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi.

In Nigeria the bulk of okra germplasm resides in the two national institutes: National Centre of Genetic Resources and Biotechnology (NACGRAB), Ibadan and National Horticultural Research Institute, Ibadan. Earlier, the University of Ibadan initiated a study involving collection of about 300 okra accessions from 13 countries including the local varieties. The results of the various studies emanating from the collections suggested high genetic variation. It is instructive to note that all the 300 collections evaluated at the University of Ibadan belonged to *A. esculentus* (Ariyo, 1990, 1993), whereas most of the local varieties belong to the Guinean okra, *A. caillei*. Evidence shows that $F_1$ hybrids between *A. esculentus* and *A. caillei* are partially sterile. This further justifies the classification of the two types into two separate species. Figure 51 shows *A. caillei* at various stages of growth in the field.

**Figure 51: *Abelmoschus caillei* at different stages of growth**

## BREEDING

Because okra is predominantly autogamous, breeding methods common to self-pollinated crops can be employed for improvement. The methods commonly employed are plant introduction, pure line selection, intraspecific and interspecific hybridization using backcross techniques, mutation and polyploidy breeding.

### Plant introduction

The cultivar 'Pusa Sawani' was developed in India and has been introduced to different okra growing regions of the world. This variety was bred as a symptomless carrier of *Yellow vein mosaic virus* (YVMV). Similarly, the variety 'Clemson Spineless Louisiana' bred in the United States has been introduced to a large number of okra-growing countries both for fresh market and canning purposes. Indigenous introductions have played a significant role in improving the okra wealth of many countries. A cultivar from Ghana identified as *A. manihot* ssp. *manihot* introduced into India has served as a source of resistance to YVMV.

### Pure line selection

In India, the first improved variety of okra, 'Pusa Makhmal' was developed through pure line selection using material from west Bengal (Singh and Sikka, 1955). The cultivar Co 1 is also a single plant selection from a heterozygous population of 'Red Wonder'. 'Gujarat Bhinda 1' is a pure line selection of unknown origin bulked seed.

### Hybridization

In India, intervarietal hybridization followed by pedigree selection produced the widely cultivated high yielding, YVMV tolerant cultivar 'Pusa Sawani' (Singh et al., 1962).

Similarly, Selection 2 is a derivative of multiple intervarietal crossing (Thomas and Prashad, 1985). Interspecific crossing has been followed in the development of 'Punjab Padmini' (Sharma, 1982), 'Winter Bush' (Martin, 1982), 'Parbhani Kranti' (Jambhale and Nerkar, 1986), 'Punjab-7' (Thakur and Arora, 1988), 'Arka anamika' and 'Arka Abhay' (Dutta, 1991). In all the above cases except 'Punjab Padmini' backcrossing was used. Using west African species, Martin (1982) inferred that backcrossing is useful for transfer of the traits of vigour, woodiness, perennialism, branched inflorescence and high number of seeds per pod, as well as disease resistance.

**Distant hybridization in *Abelmoschus* spp.**

*Abelmoschus manihot* is being extensively used in the breeding programme of okra for yellow mosaic virus disease resistance. Quite a few studies were carried out on interspecific hybridization in genus *Abelmochus* with varying degree of success (Pal et al., 1952; Siemonsma, 1982). *A. esculentus* (2n = 124) is crossable with *A. manihot* (2n = 68) and produces amphiploids (2n = 192) with the help of colchicines. *A. esculentus* is crossable with *A. muschatus* and *A. ficulneus* with special aids such as embryo and ovule culture. *A. esculentus* (2n = 130) is crossable in both direction with *A. tuberculatus* (2n = 58).

**Mutation breeding**

Efforts have been made to generate more variability through mutations (Kuwada, 1970; Nandpuri et al., 1971; Dalia, 1986; Sharma and Arora, 1991). Kuwada (1970) isolated a few promising lines in $X_{10}$ generation. According to Fatokun et al. (1979), supernumerary inflorescences were found in several plants of northern Nigerian ecotype. The mutant was controlled by a simple dominant gene. It was believed that the mutant could be grown commercially to produce a large number of fruits of acceptable size on each plant. Of all the above studies, the report of Sharma and Arora (1991) seems to be of most significance, as a mutant EMS 8 carrying resistance to YVMV and tolerance to fruit barrier has been developed through the use of ethylmetyl sulfonate.

**Polyploid breeding**

Failure of many species crosses due to hybrid sterility prompted researchers to try amphidiploids. Kuwada (1961) obtained a fertile amphidiploid by duplication of the $F_1$ between *A. esculentus* x *A. manihot* called 'Nori-Asa'. Kuwada (1966) later synthesized an amphidiploid *A. tubercular esculentus*. It has been inferred by Siemonsma (1982) that the west African okra Guinean is a natural amphidiploid of *A. esculentus* and *A. manihot*. Suresh Babu (1987) also induced amphidiploids in a cross between *A. esculentus* and *A. manihot* spp. *tetraphyllus*. The amphidiploid was highly fertile and gave 94.14% pollen stainability.

**Heterosis**

Okra has been intensively studied for heterosis. However, practical utilization of heterosis is highly restricted. Heterosis has been very well documented for yield (Singh and Singh, 1979; Elangovan et al., 1981). Number of fruits was the most important component of yield heterosis. The other components attributing to yield heterosis were plant height, fruit width, fruit height (Singh et al., 1975) and ranges of heterosis were 6.62-52.27% for yield, 0.03-39.03% for fruit number, 4.19-8.09% for fruit width, 0.31-14.27% for fruit length and 14.29-32.11% for plant height over best parent. Kulkarni et al. (1978) studied heterosis for number of fruits, plant height and days to flowering, and found heterosis of up to 12.4, 19.9 and 11.7%, respectively, over best parent.

**Breeding for quality and processing traits**

For dehydration of okra (*A. esculentus*), less fibre, less mucilaginous substances, high protein, high dry matter and minerals are important attributes. For canning and freezing, however, high chlorophyll, less crude fibre and mucilage substances, low dry matter and high protein, vitamins and minerals are required. Small tender pods should be used for canning. 'Pusa Sawani', 'Dwarf Green Smooth' and 'Vaishali Vadhu' (Kalra et al., 1982) were found to have the best quality for canning. The variety 'Pusa Sawani' was found to have the best texture, taste, flavour and dehydration and rehydration ratio. Distant hybridization can be used for the transfer of quality traits like green colour from *A. manihot* to *A. esculentus* 'Sel 2', which is suitable for freezing.

**Breeding in west African okra**

Selection and breeding of west African okra have not been carried out by the commercial sector, but African farmers have selected an enormous diversity of forms which fit into a great variety of cropping systems. Ariyo (1993) reported that there is plenty of scope for combining desirable characteristics in cultivars for the traditional sector (where handy, robust, long-lived types are required) as well as for the commercial sector (where good alternatives for introduced cultivars of *Abelmoschus esculentus* are needed with better adaptation to local conditions, diseases and pests in particular). Nevertheless, isozyme analysis has shown rather low level of genetic diversity in cultivated okra in spite of much phenotypic variability.

The characteristics of both okra species open up new opportunities for recombination if only the interspecific sterility can be overcome. *Abelmoschus esculentus* 'Parbarani Kranti' was bred in this way in India, with YVMV resistance/tolerance derived from *Abelmoschus caillei*. Although, they occur together in farmers' field, the genetic integrity of the two okra species is largely assured because chances are very small that the unproductive $F_1$ hybrids will be selected as seed sources for the next crop.

**CROP PRODUCTION PRACTICES**

Well established crop is necessary for the utilization of agricultural inputs thereby enhancing productivity. The most common method used to plant okra is direct seeding. Okra is better planted from seed, it does not transplant well. The seeds are occasionally mixed with wood ashes or soaked in water. They can be soaked overnight in water before planting. The seeds are often planted directly in the ground. When directly seeding okra, it is important to make sure that the soil is warm enough. Soil temperature should be at least 50-70°C. Farmers in tropical Africa seldom plant okra by transplants in their mixed systems. However, when okra is transplanted, hardened seedlings are usually transplanted to well-prepared, moist soil. The seedlings are usually exposed to outside light and temperature gradually over a period of 5-7 days. If this method is adopted at all, it may be ensured that the soil is wet, preferably during the rainy season. Seedlings are ready for transplanting when they reach a height of 10-15 cm and are planted in rows.

**Land preparation**

There is no general consensus among tropical African farmers as to how land is prepared for okra. However, farmers take into account the agro-ecological location, soil fertility and plant nutrition, mode of cropping, season and crop types in land preparation. Thorough land preparation prior to planting is often recommended for okra to allow organic matter in the soil to break down. Okra is generally planted on ridges in heavy clay soils for good drainage, and with lots of organic matter. In mixtures with staple food crops, okra is planted in furrows or along the base of the raised mounds on either side of the main crop. Okra is also planted on a flat bed with field crops on newly cleared land after trash burning.

Okra seeds sown directly or seedlings transplanted into the field planted with the main crop often assume the usual spacing of the associated main staple crop. The density of planting depends on the variety, size of the mounds, and number of stands per mound. When early-maturing, dwarf, less vigorous okra varieties are grown with crops like yams, 2-3 plants may be sown per mound, depending on the size of the mound. However, for commercially grown okra, the ridges or rows are usually spaced about 60-100 cm apart, with about 20-30 cm between plants. The seed rate is 3.0-7.5 kg $ha^{-1}$, this gives a planting density of 20 000-50 000 plants $ha^{-1}$. For vigorous genotypes of okra like *Abelmoschus caillei* (A.Chev Stevels) wider spacing is required. Okra is also planted in a zig-zag pattern in a flat bed 60-120 cm wide. The bed may carry about 3-4 rows of okra plants. Okra will grow best in soil which has been tilled 15-25 cm deep (Olasantan, 2009).

**Soil fertility and plant nutrition**

This is an important component in vegetable production in tropical Africa. Okra benefits from side dressings of both organic and inorganic fertilizers. However, the use of inorganic fertilizers is hampered by the prohibitive costs, non-availability and inadequate knowledge of the application technology. Fertilizer use in tropical Africa also depends on agro-ecological location, season and crop variety.

In most African countries, the trend in fertilizer use has always reflected government policies. The nature of fertilizer distribution and use has varied a great deal in tropical Africa and it is difficult to adequately monitor national trends in the use of this commodity, particularly for vegetables. It is difficult to determine what quantities of fertilizers are used solely for vegetables such as okra. This makes it difficult to predict the future need for fertilizers in vegetable production (Olasantan, 1994). Although over the last 20 years the use of fertilizers has continued to increase, African countries still rank among the lowest fertilizer users in the world. The tropical world, particularly Africa, is notoriously poor in its level of fertilizer application to crops (FAO, 1986).

Response of okra to N fertilizer application depends on the mode of production. For instance, Olasantan (1991) found that application of 60 kg N $ha^{-1}$ in the sole crop and 30 kg N $ha^{-1}$ in mixtures with cowpeas increased fresh pod yields of okra. Olasantan (1999) also observed that application of 120 kg N $ha^{-1}$ in mixtures with cassava and maize did not result in a further significant gain in pod yield of the associated okra crop. Olasantan (1998) has reported good pod yields of okra with application of 90 kg N $ha^{-1}$ after the preceding maize crop and with application of 45 kg N $ha^{-1}$ after the preceding cowpea crop in both sole and mixed stands. Okra responds differently to rate or type of organic manures. Application of 2-3 t $ha^{-1}$ poultry based organo-mineral fertilizer, or 2-6 t $ha^{-1}$ goat manure plus 40 kg $ha^{-1}$ urea or 5-7.5 t $ha^{-1}$ compost is required for okra production. The manure must be applied about 2 weeks before sowing.

**Irrigation and water management**

Okra needs warm and moist soil to grow well; that is not a problem in tropical Africa. After proper land preparation 3 or 4 seeds are sown per stand and later thinned to one or two healthy plants. Although okra seeds need to be kept evenly moist throughout the growing season, it will do fairly well under relatively dry conditions. Okra is susceptible to saline conditions, so good quality water is imperative for its production. Under dry conditions, watering every week will give higher yields. However, sandy soils usually will need water more often than clay soils.

Okra is a heavily foliaged vegetable that requires a high amount of water for growth. No accurate figures on amount and regularity of water required can be given as this will vary tremendously depending on locality, time of the year, soil type and type of irrigation required.

As a general guideline, the crop could be expected to use 7 ML $ha^{-1}$ under sprinkler irrigation, 4-6 ML $ha^{-1}$ using drip irrigation and up to 8-10 ML $ha^{-1}$ using furrow irrigation. For overhead-irrigated okra plants, water exceeding 1.6 dS $m^{-1}$ EC should be avoided. In furrow and trickle irrigated crops, water up to 2-4 dS $m^{-1}$ EC can be used. In tropical Africa, okra is mainly grown during the rainy season and for good reasons. The crop is easy to grow then as water is available and farmers can conveniently avoid the cost of irrigation. In southern Nigeria, for instance, the rainy season is long, rainfall is plentiful and bimodal, permitting two or three okra crops per year.

**Integrated diseases and plant management**

Weed control is necessary throughout the life cycle of the okra crop. Cultivation around the okra plants to remove weeds during the first 6 weeks of growth is particularly important. The usual farming practice is to hand-pull weeds close to the plants to avoid damaging the roots of okra, although plots are generally kept weed-free manually with African hoes. This is usually done once or twice before okra plants form a full canopy to cover the ground. The objective is to keep okra plots weed-free as much as possible, especially at the early stages of crop establishment.

Typically, African farmers seldom apply herbicides to control weeds in their crops. Part of the efficiency of mixing arable crops with broad-leaf vegetables such as okra is to reduce weed growth. The weeds that might otherwise build up before the slow-canopy-closure arable crops such as yams and cassava cover the ground can be effectively suppressed by early-maturing okra plants. Furthermore, light, water and nutrients, which otherwise might be wasted and/or used by weeds before the late-maturing arable crops form full canopy, can be largely utilized by this vegetable. Olasantan (2001a) found a considerable reduction in weed biomass in cassava/okra intercrop, up to 22-24% compared with okra monoculture, and a further reduction of 40-45% compared with cassava monoculture at 8-10 weeks after planting, irrespective of okra population density. Olasantan and Bello (2004) also reported that in cassava/okra intercrop, weed dry weight yield was 15-22% lower compared with okra grown alone and 35-57% lower compared with sole cassava crop, regardless of okra sowing date.

Okra can to some extent tolerate young leaf defoliation by insects or harvest for food. For instance, removing apical bud leaves at 4 or 5 weeks and a single young leaf at 3-week intervals is not detrimental to okra grown for both leaves and pods (Olasantan, 1986, 1988). Also, removing 2 or 3 uppermost branches of okra plants for food as a vegetable had no detrimental effect on pod yield (Olasantan and Salau, 2008). The implication of this is that okra can tolerate considerable branch or leaf damage, about 25% defoliation during vegetative growth stage as can happen with young leaf harvest or insect damage, without serious loss of pod yield. During the early establishment stages, however, okra is highly susceptible to leaf damage by insect pests. Common diseases and pests of okra are shown in Table 31.

Management of pests and diseases is another important aspect of the efficiency of growing vegetables in mixed systems in tropical Africa. Most farmers who grow okra rarely use pesticides to protect it against pests and diseases. They depend mainly on the effectiveness of the biocultural protective measures of their mixed systems. Crop associations have different ways in which they escape major diseases and insect attack. The system provides durable ecological protection against disease development and insect and nematode attack on the host plants (Thenbath, 1993). This is achieved by interfering directly with the odour of the host plants and with the physical movement of the pathogenic organisms and insect pests from one susceptible host plant to another.

**Table 31: Common pests and diseases of okra**

| Pests | Diseases |
|---|---|
| • Leaf feeder or leaf eating beetle: The larvae feed on leaves, cut and fold them.<br>• Pod borer: Bores into shoots, buds and young pods leaving wet brown mass at infested points.<br>• Sucking pest: Soft bodies, green, pink, red or brown aphid, usually on underside of leaves, sucks plant sap.<br>• Red cotton bug: Nymphs and adults suck sap from shoot, leaves, flowers and young fruits. The fruits become deformed.<br>• Root knot nematodes: Irregular-shaped galls attached to the roots caused by eelworm or root-knot nematodes (*Meloidogyne* spp.). Growth and pod yields are reduced due to secondary infection by fungi in the roots. | • Leaf mold: Occurs on the undersurface of leaves which later turn yellow and dry up.<br>• Mosaic virus: Leaves become mottled and distorted.<br>• *Fusarium* wilt: Attacks plants at the base at soil level.<br>• Damping-off: Caused by soil fungi including *Pythium, Rhizoctonia*, etc. |

Furthermore, by changing the growth environment (light, temperature and relative humidity) in the mixtures natural enemies of the attackers are favoured. For instance, the numbers of insect pests such as *Podagrica* species and *Sylepta derogata* and root-galls per okra plant caused by root-knot nematodes were about 30% lower in okra intercropped with cassava or yam, where light penetration is lower, soil temperatures were lower and soil moisture was greater, than when grown in monoculture (Olasantan, 2001a). In southern Nigeria, where half of the area grown with food crops and okra is planted with *Amaranthus* spp., damage levels from *Meloidogyne* spp. are very low (Messiaen, 1994).

## CROPPING SYSTEMS

Okra is commonly found growing in fields, contributing to the total amount of produce harvested and socio-economic needs of farmers (Olasantan, 2001b). Attempts to diversify okra production in tropical Africa must therefore be based on the exploitation of the mixed systems. In Nigeria, any intercropping technologies that exclude vegetable crops in mixed systems are not acceptable to farmers (Ikeorgu et al., 1989; Olasantan, 1992, 2001b).

In tropical Africa, okra is mainly intercropped with field crops such as yam, cassava, maize, food legumes, etc. As indicated by Coursey (1967) and Anonymous (1988), field crops such as maize, yam and cassava are the important staple foods for 160-200 million people, mostly in west and central Africa. African farmers cannot entertain the reduction of their crop production to make arable land available for other crops. Moreover, good arable land is scarce in Africa because of increased population growth. Cassava and yams are long-duration crops that occupy the land for 6-12 months. They are usually planted in wide-spaced ridges, early when the rains begin, and their initial growth and canopy development are slow. It is uneconomical to grow these crops alone for such a long period, but their cultivation system and growth habits provide a good opportunity for intercropping with vegetables to enhance total production and other beneficial attributes of the system.

The factors that affect vegetables and the nature of interactions in mixed systems include plant population density, stand geometry, arrangement of component crops in space and time dimensions, crop combinations, time and duration of crop interactions, and availability and utilization of soil moisture, nutrients and light. The following discussion of okra production in mixed systems focuses on plant population density and fertilizer use in sole and mixed systems.

### Okra plant populations in mixed systems

The characteristics of the species being grown, population density, and plant and row spacing used are aspects of cropping practices that influence the production of okra in mixed systems. Scientists studying mixed cropping systems with vegetables are faced with altering plant population density of the component species without significantly modifying stand geometry and reducing crop yield. In plant population studies in mixed systems with vegetables, a wide range of population densities is needed to effectively examine interactions of component species.

Different plant population densities have been reported for okra production in various parts of the world. In Nepal, a population density of 150,000 plants ha$^{-1}$ was reported for optimal pod yields (Shrestha, 1983), whereas in Ludhiana, India, a population density of 145,000 plants ha$^{-1}$ was recommended to give maximum pod yields (Randhawa and Pannum, 1969). In the U.S.A., the yields of okra were highest at the closest spacing (122 x 5 cm) tested (Sutton and Albregts, 1970). In tropical Africa, where lowland humid tropical conditions prevail and okra is often grown in mixtures, such high populations might not be acceptable to farmers. Olasantan and Aina (1987), using projected okra population densities of 19,000-46,000 plants ha$^{-1}$ in mixed stands with cowpeas, and 35,000-66,000 plants ha$^{-1}$ in monoculture, observed that plant density did not affect quality of fresh pods and pod yields of okra grown in both cropping systems. This suggests that in both systems optimal densities were not yet reached. Okra can be intercropped with food legumes with more than 26,000 plants ha$^{-1}$ and a population density of at least 66,000 plants ha$^{-1}$ is required for good pod yields from a sole okra crop under the prevailing low land humid conditions.

In a study to evaluate the optimum population density at 25,000, 35,000 and 50,000 plants ha$^{-1}$ for okra in mixtures with cassava in the late and early-season crops (Olasantan, 2001a), okra sown at 50,000 plants ha$^{-1}$ took the longest time to reach specific phenological stages and produced the highest pod yields in both seasons. However, there was no significant difference between 35,000 and 50,000 plants ha$^{-1}$ in mixed systems in the early-season crops (Table 32). When rainfall is limiting in the late-season crops, okra can thus be intercropped with cassava using population density up to 35,000 plants ha$^{-1}$ to allow the vegetable to develop and to maximize pod yield under the relatively dry conditions. The optimum target suggested is 50,000-60,000 plants ha$^{-1}$ during the wet months, early season when water is not a constraint.

### Fertilizer recommendations for okra in mixed systems

In mixed systems, production of okra can be enhanced through soil fertility amendment. However, intercropping studies have placed little emphasis on derivation of appropriate fertilization practices in tropical Africa. The poor fertility status of most tropical soils necessitates the use of fertilizers for intense mixed cropping systems. Recommendations on fertilization of vegetables in mixed systems are still based on nutrient requirements in pure stands of main food crops (Olasantan, 1994). Olasantan (1991) found that pod yields of okra were reduced significantly with application of 60 kg N ha$^{-1}$ in intercropping with cowpeas compared with the sole okra crop (Table 33).

Furthermore, in a cassava/maize/okra complex mixture at different N rates, maize, irrespective of its cultivar, had greater effect than cassava in determining most growth and pod yield characters of the okra crop (Olasantan, 1999). Application of 60 kg N ha$^{-1}$ in sole crop or in mixtures with cassava and 30 kg ha$^{-1}$ in maize/okra or cassava/maize/okra mixtures increased marketable fresh pod yield of okra (Table 34).

**Table 32: Effect of population density on fresh pod yield and yield characters of okra in monoculture and mixed stands with cassava in late-season sowing in 1997 and early-season sowing in 1998 in Nigeria**

(Source: Olasantan, 2001a)

| Okra population/ ha | No. of pods/ plant | | Pod length (cm) | | Weight/pod (g) | | Fresh pod yield | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (g/plant) | | (t/ha) | |
| | Late 1997 | Early 1998 | Late 1997 | Early 1998 | Late 1997 | Early 1998 | Late 1997 | Early 1998 | Late 1997 | Early 1998 |
| **Monoculture okra** | | | | | | | | | | |
| 25 000 | 10 | 12 | 5.5 | 6.0 | 15.4 | 14.4 | 144 | 171 | 3.6 | 4.2 |
| 35 000 | 9 | 11 | 5.5 | 5.7 | 14.2 | 14.9 | 117 | 157 | 4.1 | 5.5 |
| 50 000 | 7 | 10 | 5.4 | 5.2 | 13.3 | 14.2 | 94 | 138 | 4.9 | 6.9 |
| **Intercropped okra** | | | | | | | | | | |
| 25 000 | 10 | 12 | 5.4 | 5.4 | 14.8 | 15.2 | 133 | 187 | 3.3 | 4.4 |
| 35 000 | 8 | 10 | 4.5 | 6.1 | 14.4 | 15.0 | 115 | 149 | 4.0 | 5.4 |
| 50 000 | 6 | 9 | 4.4 | 5.5 | 13.9 | 14.7 | 84 | 137 | 4.2 | 6.8 |
| S.E. (cropping x population) | 1.15 | 1.27 | 0.21 | 0.17 | 1.20 | 1.36 | 12.3 | 13.9 | 0.54 | 0.61 |
| Sole crop okra | 9 | 11 | 5.5 | 5.6 | 14.3 | 14.5 | 118 | 155 | 4.2 | 5.6 |
| Okra intercrop (mean) | 8 | 10 | 4.8 | 5.7 | 14.4 | 15.0 | 111 | 158 | 3.8 | 5.5 |
| S.E. (2D.F.) (cropping) | 0.40 | 0.35 | 0.25 | 0.40 | 0.50 | 0.73 | 4.9 | 6.9 | 0.25 | 0.04 |
| 25 000 mean | 10 | 12 | 5.5 | 5.7 | 15.1 | 14.8 | 139 | 179 | 3.5 | 4.3 |
| 35 000 mean | 8 | 11 | 5.0 | 5.9 | 14.3 | 15.0 | 116 | 153 | 4.1 | 5.5 |
| 50 000 mean | 7 | 10 | 5.0 | 5.4 | 13.6 | 14.5 | 89 | 138 | 4.6 | 6.9 |
| S.E. (8D.F.) (population) | 0.72 | 0.77 | 0.12 | 0.71 | 0.71 | 0.99 | 8.7 | 10.4 | 0.38 | 0.46 |

**Table 33: Fresh pod yield and yield characters of okra in sole cropping and intercropping at different nitrogen fertilizer rates in two years**

(Source: Olasantan, 1991)

| Nitrogen rate (kg ha$^{-1}$) | No. pods/plant | | Weight/pod (g) | | Pod weight (g/plant) | | Pod yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|
| | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 |
| **Sole cropping** | | | | | | | | |
| 0 | 8.2 | 7.5 | 13.3 | 16.4 | 113 | 126 | 4.2 | 4.6 |
| 30 | 10.3 | 9.1 | 11.7 | 15.7 | 123 | 148 | 4.6 | 5.5 |
| 60 | 11.0 | 10.2 | 12.0 | 15.8 | 134 | 168 | 5.0 | 6.1 |
| Mean | 9.8 | 8.9 | 12.3 | 16.0 | 123 | 146 | 4.6 | 5.4 |
| **Intercropping** | | | | | | | | |
| 0 | 8.5 | 6.7 | 12.5 | 15.2 | 108 | 103 | 2.0 | 2.1 |
| 30 | 9.9 | 8.5 | 12.7 | 17.0 | 130 | 146 | 2.4 | 2.7 |
| 60 | 8.4 | 7.2 | 12.8 | 16.1 | 112 | 119 | 2.1 | 2.2 |
| Mean | 8.9 | 7.5 | 12.7 | 16.1 | 117 | 123 | 2.2 | 2.3 |
| **LSD (P= 0.05)** | | | | | | | | |
| Cropping | n.s. | 0.65 | n.s. | n.s. | n.s. | 21.83 | 0.23 | 0.52 |
| N | 0.46 | 0.66 | n.s. | n.s. | 9.22 | 11.38 | 0.33 | 0.41 |
| Cropping x N | ** | ** | n.s. | n.s. | * | ** | * | * |

n.s. = not significant, *=significant at $P \leq 0.05$, **= significant at $P \leq 0.01$

**Table 34: Pod yield characters of okra intercropped with cassava and maize cv. TZE Composite 3 (EM) or cv. DMRSR-Y (LM) at different rates of applied nitrogen in 1995 and 1996 in Nigeria**

(Source: Olasantan, 1999)

| Cropping system (kg N/ha) | Days to first harvest | | No. of pods/plant | | Weight/pod (g) | | Pod yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 | 1995 | 1996 |
| **Sole crop** | | | | | | | | |
| 0 | 67 | 61 | 5 | 6 | 11 | 13 | 2.2 | 2.6 |
| 30 | 64 | 59 | 7 | 8 | 14 | 15 | 3.3 | 4.3 |
| 60 | 61 | 58 | 9 | 9 | 14 | 14 | 4.6 | 5.9 |
| **Cassava/okra** | | | | | | | | |
| 0 | 68 | - | 6 | - | 9 | - | 1.2 | - |
| 30 | 65 | - | 7 | - | 11 | - | 3.0 | - |
| 60 | 61 | - | 8 | - | 12 | - | 4.2 | - |
| **Maize/okra** | | | | | | | | |
| 0 | 76 | - | 4 | - | 6 | - | 0.7 | - |
| 30 | 71 | - | 6 | - | 9 | - | 2.1 | - |
| 60 | 71 | - | 4 | - | 11 | - | 1.8 | - |
| **Cassava/maize (EM)/okra** | | | | | | | | |
| 0 | 77 | 67 | 4 | 5 | 6 | 14 | 0.8 | 2.0 |
| 30 | 75 | 65 | 5 | 7 | 11 | 14 | 2.2 | 2.8 |
| 60 | 73 | 65 | 5 | 6 | 8 | 14 | 1.9 | 2.7 |
| **Cassava/maize (LM)/okra** | | | | | | | | |
| 0 | - | 66 | - | 5 | - | 12 | - | - |
| 30 | - | 64 | - | 6 | - | 13 | - | - |
| 60 | - | 63 | - | 6 | - | 13 | - | - |
| S.E. (16 or 12 D.F.) (cropping x N) | 2.7 | 3.1 | 0.35 | 0.19 | 1.24 | 0.17 | 0.33 | 0.10 |
| Sole okra (mean) | 64 | 59 | 7 | 8 | 13 | 14 | 3.4 | 4.3 |
| Cassava/okra (mean) | 65 | - | 7 | - | 12 | - | 3.0 | - |
| Maize (EM)/okra (mean) | 73 | - | 5 | - | 9 | - | 1.5 | - |
| Cassava/maize (EM)/okra (mean) | 75 | 66 | 5 | 6 | 8 | 14 | 1.6 | 3.5 |
| Cassava/maize (LM)/okra (mean) | - | 64 | - | 6 | - | 13 | - | 2.5 |
| S.E. (6 or 4 D.F.) (cropping) | 1.9 | 1.5 | 0.22 | 0.41 | 0.65 | 0.15 | 0.20 | 0.20 |
| 0 (mean) | 72 | 65 | 5 | 5 | 8 | 13 | 1.3 | 2.3 |
| 30 (mean) | 69 | 63 | 6 | 7 | 11 | 14 | 2.7 | 3.5 |
| 60 (mean) | 67 | 62 | 7 | 7 | 11 | 14 | 3.1 | 3.9 |
| S.E. (16 or 12 D.F.) (N rate) | 1.3 | 1.8 | 0.17 | 0.11 | 0.63 | 0.10 | 0.16 | 0.06 |

EM, Early-maturing; LM, Late-maturing

## N-fertilization of okra in mixed and alley cropping with woody and grain legumes

Scarcity and steep rise in the prices of nitrogen fertilizers in tropical Africa have encouraged a search for alternative sources of nitrogen. This has led to renewed interest in biological N-fixation in mixed cropping and alley cropping systems. In an attempt to determine the contribution of preceding maize and cowpea grown in pure and mixed stands to succeeding okra plants, Olasantan (1998) reported that application of 90 kg N $ha^{-1}$ after maize crop and 45 kg N $ha^{-1}$ after cowpeas, grown either in sole or mixed stands, gave the highest pod yields for a succeeding okra crop (Table 35).

**Table 35: Effect of preceding crops and nitrogen application on leaf area, fresh pod yield and yield characters of okra in 1992 and 1993 in Nigeria**

(Source: Olasantan, 1998)

| Nitrogen rate (kg/ha) | Leaf area ($cm^2$) | | No. of pods/plant | | Weight/pod (g) | | Green pod yield (g/plant) (t/ha) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1992 | 1993 | 1992 | 1993 | 1992 | 1993 | 1992 | 1993 | 1992 | 1993 |
| **Sole crop maize** | | | | | | | | | | |
| 0 | 1232 | 1176 | 8 | 8 | 12.1 | 12.6 | 101 | 105 | 4.6 | 4.7 |
| 45 | 1289 | 1298 | 9 | 10 | 13.1 | 13.0 | 119 | 129 | 5.5 | 5.8 |
| 90 | 1369 | 1352 | 12 | 12 | 14.2 | 14.4 | 161 | 168 | 7.2 | 7.4 |
| Mean | 1297 | 1275 | 10 | 10 | 13.1 | 13.3 | 127 | 134 | 5.8 | 6.0 |
| **Sole crop cowpea** | | | | | | | | | | |
| 0 | 1223 | 1264 | 10 | 9 | 12.4 | 13.6 | 129 | 123 | 5.8 | 5.5 |
| 45 | 1358 | 1370 | 11 | 11 | 14.8 | 14.2 | 163 | 153 | 7.4 | 7.1 |
| 90 | 1503 | 1472 | 11 | 11 | 14.4 | 15.0 | 158 | 165 | 7.2 | 7.4 |
| Mean | 1361 | 1369 | 11 | 10 | 13.9 | 14.3 | 150 | 147 | 6.8 | 6.7 |
| **Maize/cowpea intercrop** | | | | | | | | | | |
| 0 | 1335 | 1264 | 9 | 10 | 14.2 | 13.2 | 119 | 130 | 5.4 | 5.9 |
| 45 | 1373 | 1426 | 11 | 12 | 14.4 | 14.0 | 157 | 164 | 7.2 | 7.5 |
| 90 | 1430 | 1538 | 11 | 11 | 15.0 | 14.8 | 165 | 162 | 7.4 | 7.3 |
| Mean | 1379 | 1409 | 10 | 11 | 14.5 | 14.0 | 147 | 152 | 6.7 | 6.9 |
| **S.E. (Error)** | | | | | | | | | | |
| Preceding crop (4 D.F.) | 30.5 | 32.3 | 0.33 | 0.19 | 0.36 | 0.15 | 4.99 | 3.96 | 0.22 | 0.20 |
| N rate (12 D.F.) | 29.7 | 32.1 | 0.40 | 0.25 | 0.42 | 0.24 | 3.94 | 3.85 | 0.17 | 0.19 |
| Preceding crop x N (12 D.F.) | 60.1 | 64.6 | 0.73 | 0.45 | 0.78 | 0.40 | 8.99 | 7.82 | 0.39 | 0.38 |

In Gliricidia (*Gliricidia sepium*) alley cropping system, application of 30 kg N $ha^{-1}$ with hedgerow pruning applied significantly increased pod yield of okra compared with application of 60 or 90 kg N $ha^{-1}$ (Olasantan, 2000) (Table 36).

**Table 36: Effect of nitrogen application on fruit yield and yield components of okra with hedgerow pruning applied as mulch in *Gliricidia sepium* alley cropping system in 1993 and 1994 in Nigeria**

(Source: Olasantan, 2000)

| Nitrogen rate (kg/ha) | No. of fruits/ plant | | Weight/fruit (g) | | Pod yield (g/plant) (t/ha) | | | |
|---|---|---|---|---|---|---|---|---|
| | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 | 1993 | 1994 |
| 0 | 7.3 | 8.3 | 16.3 | 15.7 | 128 | 131 | 4.7 | 4.6 |
| 30 | 10.8 | 11.3 | 17.0 | 16.3 | 178 | 185 | 6.7 | 6.8 |
| 60 | 9.3 | 12.3 | 16.0 | 16.0 | 142 | 197 | 5.3 | 7.3 |
| 90 | 8.3 | 8.7 | 16.0 | 15.7 | 133 | 137 | 4.9 | 5.1 |
| Mean | 8.9 | 10.2 | 16.3 | 15.9 | 145 | 163 | 5.4 | 6.0 |
| LSD (P=0.05) | 1.23 | 0.94 | 1.28 | 1.05 | 36.4 | 23.2 | 1.29 | 0.88 |

The complementary effects of alley cropping (woody legumes) and preceding grain legumes on okra were thus manifested at lower N rates. Growing vegetables in alleys formed by hedgerows of N-fixing leguminous species therefore deserves special attention. Soil fertility aspects of alley cropping have been extensively examined (Kang et al., 1984; Hulugalle and Kang, 1990; Siaw et al., 1991). Earlier studies on food legume/okra intercrop without basal fertilizer treatments indicated complementary effects between the intercrops (Olasantan and Aina, 1987; Olasantan, 1994). Adequate information about the beneficial effects of woody and grain legumes on okra is, therefore, imperative as intercropping with legumes can be adopted as a cheaper alternative source to N fertilizers.

## POST-HARVEST MANAGEMENT

### Harvesting

Timely harvesting promotes more yield and produces more marketable tender and nutritious pods. Harvesting of okra fruits depends on the variety, cropping systems, disposition and cultural practices such as mode of planting and fertilizer application. These factors have considerable bearing on storage life and quality of the produce. Horticultural or commercial maturity is that stage of development when okra possesses the prerequisites for utilization by consumers for a particular purpose, be it for fresh pods or dry seeds.

Maturity in okra is judged by visual examination of colour, size and shape, and by feeling the texture such as hardness or softness. Normally, okra pods are harvested when they are tender and exhibit maximum growth rate. At this stage, the blossom end of the fruit, when bent, snaps easily. Okra should be harvested when the fruits are bright green, the pods are fleshy, and the seeds are small. After that period, the pods become pithy and tough, and the green colour and mucilage content decrease. Okra pods are ready for harvesting 5-7 days after fruit set. Iremiren et al. (1991) found that pods harvested more than 7 days after pod set were of low quality mainly due to an increase in crude fibre and a reduction in moisture, crude protein, and ash content.

### Processing

Processing is to prevent wastage and to make available the crop all the year round thereby increasing returns on investment. Processing is undertaken in okra production in order to make perishable pods into a more durable form. A considerable amount of okra is processed by drying, freezing, and canning. Okra fruits are also preserved in brine after boiling or dried in the sun or oven in slices, mostly in Africa and India.

Drying is one of the age-old methods of preservation. The principle of drying is the removal of moisture. The pods are washed thoroughly to remove dirt, both ends are trimmed and any discoloured or damaged tissue is removed. Young tender pods are preferred and they may be dried whole or in the form of slices (about 6 mm thick) or in halves cut lengthwise. In order to preserve well or keep the green colour, blanching is carried out. The product is dipped for 3 minutes in boiling water containing 50 g salt per litre of water. Inyang and Ike (1998) reported that blanching freshly harvested okra fruits in boiling water (with or without 0.2% sodium metabisulfite) resulted in a slight decrease in carbohydrate, fat, ash, colour components, ascorbic acid, and viscosity. They also reported that blanching in sulfite solution followed by dehydration led to the retention of more of the colour components and ascorbic acid. The quality of the dried product was best when okra was sliced and blanched at 95°C in 0.5% NaCl solution for 5 minutes and then dried at 55°C (Shivhare et al., 2000). The storage life of dried product is about 12 months (Susanta and Behera, 2009).

**Packaging**

Packaging increases the shelf life of okra and makes it available where needed. This enhances it value and brings more returns. Packing is important for marketing and distribution of okra pods. In Nigeria, bulk packaging of okra fruits is preferably undertaken in palm-front baskets or plastic bowls. This practice protects the produce against undue damage during distribution, maintains a high relative humidity, facilitates natural cooling, and partly removes field heat. Packing in palm-front baskets is helpful in enhancing free aeration and to prevent both wilting and physical injury during handling. Singh et al. (1980) observed that okra ('Pusa Sawani') fruits packed in 100-400 gauge polyethylene could be stored up to 9 days at room temperature (32±2°C). They reported that fruits packed in 400 gauge polyethylene had the longest shelf life (9 days) and pod retention of chlorophyll a and b was greater in packed than in control pods.

**Storage/preservation**

The importance of storage is to provide an environment that minimizes deterioration until the product is finally consumed. Okra pods in good condition can be stored satisfactorily for 7-10 days at 7-10°C. At higher temperatures, toughening, yellowing, and decay are rapid. A relative humidity range of 85-95% is desirable to prevent shriveling. At temperatures below 7°C, okra pods are subjected to chilling injury, which is manifested by surface discoloration, pitting, and decay. Holding okra pods for 3 days at 0°C may cause severe pitting (Scholz et al., 1963).

## CONCLUSION

For sustainable agricultural production good agricultural practices must be employed. The right combination of agriculture inputs and the right timing will lead to optimum productivity and production which is the ultimate goal in all agricultural enterprises.

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# Production Practices of Pumpkins for Improved Productivity

**Mel O. Oluoch**[1,2]

[1]*AVRDC-The World Vegetable Center, P.O Box 10, Duluti, Arusha, Tanzania*
[2]*International Institute of Tropical Agriculture (IITA), P.M.B. 3112, Kano, Nigeria*
*(m.oluoch@cgiar.org)*

**Abstract**

Pumpkins belong to the family *Cucurbitaceae*, and genus *Cucurbita*. The most common cultivated species in Africa are: *Cucurbita pepo* L., *Cucurbita moschata* Duch., and *Cucurbita maxima* Duch. Pumpkins are warm season crops that are sensitive to cool temperatures and frost intolerant. Most are day neutral and sex expression is monoecious. Pumpkins require soils that are fairly fertile, and well drained. Maximum yields are achieved on medium-textured soils with high water-holding capacity and good internal drainage**.** They can be grown on a wide range of soils, although heavy clay soils are not recommended. They are sensitive to salinity and acid conditions, but will grow well on slightly acidic (pH 6.8) to moderately alkaline (pH 8.0) soils. A crop rotation cycle of 2-3 years years between planting members from the *Cucurbitaceae* family is required when pathogen populations are very high. Maize, sorghum or legumes like cowpea and beans are good rotation crops. Pumpkins are generally grown on raised beds (15 to 20 cm high) with a final spacing of the beds in furrow irrigated culture generally 2 m center-to-center. Grass and plastic mulch is recommended for weed control, to keep fruit clean, and for moisture conservation. Planting is by direct seeding. Fertilizer requirements are moderate compared with many other vegetable crops (50 to 110 kg/ha). Germination is slow and erratic when soil temperature is below 20°C. Fruit maturing when daily mean air temperatures are below 20°C have poorer quality. Pumpkins do well in hot weather, but very high temperatures (43-46°C) can cause flower drop, temporary vine wilting, sunburned fruit, and soft fruit at harvest with reduced shelf life. Large fruited cultivars are often planted 1.8 to 2.4 m apart. Closer spacings produce smaller fruit while wider spacings result in larger fruit**.** Growing under trellis system increases leaf and fruit yields compared to open ground system. Environmental and disease factors can significantly influence flowering, pollination and fruit set. Pumpkins should be harvested when mature to allow for longer storage. They are often "cured" at 24-30°C and 80% high relative humidity (RH) for 5 to 10 days before long-term storage to heal any wounds that may occur during harvest.

## INTRODUCTION

Traditional crops including the pumpkins, which are rich in micronutrients, are not consumed widely by smallholder farmers in Africa. However, cultivation of high yielding, nutrient rich, multipurpose crops like pumpkin are important in solving the problems of malnutrition and contributing to food security in sub-Saharan Africa. Pumpkins are used as food and vegetables for consumption and both a commercial and home garden crop. The multipurpose uses of pumpkins, their great diversity and adaptation to a wide range of environments indicate the potential of this crop. The most common product, popular in most African countries, is the cooked mature fruit. In Zambia the ripe fruit flesh is dried for longer preservation (Grubben and Chigumira Ngwerume, 2004). On the other hand, in southern Africa the leaves are widely consumed as a leading leafy vegetable during the rainy season. In Zambia, 40% of the households use pumpkin leaves as relish daily during the rainy season. In some parts of Zimbabwe, pumpkin leaves are the most popular leafy vegetable. In Cameroon and other parts of central and west Africa *Cucurbita moschata* sp. is mainly grown for the

ripe seeds. The seeds are first roasted, the shells removed, and squashed into a paste and consumed with the main dish. Roasted seeds are also salted and eaten as a snack. The seed oil is edible and used as fuel (Grubben and Chigumira Ngwerume, 2004). However, the majority of farmers in the Lake Victoria basin of Kenya, Uganda and Tanzania do not consider pumpkins as a priority food and commercial crop and are largely utilizing it for home consumption (Ondigi et al., 2008). They are mostly grown by low income members of the community who mainly utilize the leaves as vegetables and occasionally utilize the fruit when cooked (Ondigi et al., 2008).

Despite its potential, little research has been carried out on pumpkin and information on best production practices and varietal recommendations is still scarce in Africa. Additionally, indigenous knowledge required to improve on the production practices is not well documented. In east Africa, the research and development of the crop has been neglected partly because few people use it as a staple crop (Hamisy et al., 2002). The development of best production practices of pumpkin in Africa is important to help improve productivity and utilization and reduce genetic erosion. It is therefore necessary to overcome the key constraints in research and development of pumpkins.

**Type and classification**

Pumpkins belong to the family *Cucurbitaceae*, and genus *Cucurbita*. They are warm-season, frost sensitive annuals. The cultivated species are: *Cucurbita pepo* L., (pumpkin, winter squash, summer squash, gourds); *Cucurbita moschata* Duch. (pumpkin, winter squash); *Cucurbita maxima* Duch. (pumpkin, winter squash) and *Cucurbita argyrosperma* Pang. (pumpkin, gourds). The differences between pumpkin and squash have never been clearly resolved. Culinary definitions are most often used. In some cases, only *C. pepo* are considered as true pumpkins and all *C. maxima* are considered as squash but this is by no means universal. A pumpkin is a mature fruit with coarse flesh and strong flavor. Another way to think of a pumpkin is a squash with a particular appearance. Winter squash or pumpkin is a mature fruit which is fine grained, with mild flavor and the flesh is steamed or baked for human use. Winter squash and pumpkins have long straight stems, with climbing habit although bush habits are available. Most cultivars mature in 80 to 120 days or longer. They come in different shapes and sizes (Figure 52). A summer squash is an immature fruit used in various forms and can be boiled, baked, fried, etc. as human food. It has a common bush habit and most cultivars mature in 45 to 60 days. A gourd is a mature fruit usually inedible with hard rind, used for ornamental purposes or for household utensils.

It is often not easy to distinguish the three most common species grown in Africa - *Cucurbita moschata* plants or fruits from the related *Cucurbita pepo* L. and *Cucurbita maxima*. The plant habit is similar and the fruit shape and size are variable. Distinction is easiest by observing differences of the fruit stalk, stems and leaves. They comprise many of the large fruited pumpkins. *Cucurbita moschata* has a hard, smoothly angled fruit stalk widened at apex, hard, smoothly grooved stems and soft, moderately lobed leaves. *Cucurbita maxima* has a soft, rounded fruit stalk not enlarged at apex, soft, rounded stems and soft, usually unlobed leaves. *Cucurbita pepo* has an angular fruit stalk sometimes slightly widened at apex, hard, angular, grooved, prickly stems and palmately lobed, often deeply cut and prickly leaves.

In Africa, the most common pumpkin species is *Cucurbita moschata* and many landraces occur (Figure 52). *Cucurbita moschata* is a highly appreciated, multipurpose vegetable, easy to cultivate, potentially high yielding and with a high nutritional value. It has been neglected by formal research. In Africa, traditional cultural practices are still extensive but yield levels are low; (almost) no breeding for yield, disease resistance and quality is being performed. With the introduction of improved cultivars, ancient landraces are in danger of disappearing. Germplasm collection of African landraces deserves priority. In addition to development of

improved cultivars for the fruits, attention should be paid to production practices to enhance the potential of the leaves as food, and to seed as a source of vegetable fat and protein.

**Figure 52: Different fruit shapes of pumpkin (*Cucurbita moschata*) accessions showing diversity at AVRDC-The World Vegetable Center, Arusha, Tanzania**

## PRODUCTION AND CULTURE

Pumpkins are warm season crops that are sensitive to cool temperatures and frost intolerant. They are cross pollinated and most are day neutral and sex expression is monoecious.

### Site selection

Pumpkins require soils that are fairly fertile and well drained. *Maximum yields are achieved on medium-textured soils with high water-holding capacity and good internal drainage.* They can be grown on a wide range of soils, although heavy clay soils are not recommended. Clay soils generally have poor aeration and restricted drainage, which can be detrimental to root growth and increase fruit rot. Pumpkins are sensitive to acid conditions, but will grow well on slightly acidic (pH 6.8) to moderately alkaline (pH 8.0) soils. Pumpkins and squash are quite sensitive to salinity. A crop rotation cycle of several years between planting members from the family *Cucurbitaceae* is required if pathogen populations are very high. When possible, maize, sorghum or legumes like cowpea and beans are good rotation crops.

### Field preparation

Prepare the land to ensure establishment of a uniform stand. Turn the soil several months before planting so that crop residues can fully decompose. Early land preparation also allows time for weed seeds to germinate, allowing for early cultivation to destroy young weeds. Pumpkins are generally grown on raised beds (15 to 20 cm high). Final spacing of the beds in furrow irrigated culture is generally 2 m center-to-center. Many farmers in Africa grow pumpkins without irrigation. Grass mulch is sometimes used for pumpkin production primarily for weed control, to keep fruit clean, and for moisture conservation since earliness is not a big issue. Planting is by direct seeding or occasionally transplanting. Seeds should be planted to a depth of 2 to 4 cm. To achieve the maximum stand, plant two to three seeds per hill and thin to a single plant, leaving only the healthiest seedling. For large commercial plantings, sow four seeds per 30 cm and thin to desired spacing.

## Fertilizer/nutrition

With proper care, pumpkins can be grown on most soils in Africa. However, for improved productivity, avoid low, poorly drained soils. Plant in well-drained, sandy loams with high levels of organic matter and a pH of 6.0 to 6.5. If irrigation is available, then raised beds should be used. To avoid potential soil-borne diseases and nematode problems, pumpkins should be planted in soils that have not grown a crop of watermelons, cucumber, muskmelons (cantaloupes), summer (zuchini) squash, or other member of the cucurbit family in the past 2 to 3 years.

Pumpkins and squash tend to develop extensive root systems that efficiently explore the soil for water and available nutrients. For this reason, fertilizer requirements are moderate compared with many other vegetable crops. Timely and appropriate applications of fertilizer can make a significant difference in the quality and quantity of fruit produced. In the cool seasons, collect soil samples from each area you intend to crop and have a soil analysis performed on each sample. Soil testing eliminates much of the guesswork involved in a fertilizer program. If you do not have soil testing service available nearby, which is common in Africa, then apply enough fertilizer to supply 60 kg/ha of nitrogen. At 3 and 6 weeks after sowing, side dress 15 to 20 cm deep to the side of the plants with 22 to 34 kg/ha of nitrogen and 70 to 110 kg/ha of potassium. Optimal potassium levels will ensure good dry-matter production.

Nitrogen (N) is the most commonly required fertilizer, although phosphorous is sometimes needed to promote good seedling vigor, maximum production and high fruit quality, especially in alkaline soils. Most mineral soils contain adequate potassium, but it may be deficient in areas with light soils. Phosphorus fertilizer is commonly placed in twin bands 15 cm deep and 15 to 20 cm to either side of the seed lines before planting. Banding of fertilizer near the seed is preferred over broadcast application since the rows are very far apart and in some cases making broadcast applications inefficient. Nitrogen is commonly applied in two side-dressings, the first at the 2-4 leaf stage and the second when vines start to develop runners. The goal is to grow plants with a large canopy of leaves, maintaining healthy leaves as long as possible. This can be done by maintaining adequate levels of fertilizer. However, care must be taken to not over-fertilize the crop, especially with nitrogen. *Excessive nitrogen favors vegetative growth over reproductive growth and can inhibit fruit set.* The nitrogen level must be low enough by the time of flowering so that the plant will form fewer new leaves after fruit begin to grow. This allows more sugars to go to the fruit, rather than to developing leaves and vines.

## Planting and production

Pumpkins are generally planted from seed. The minimum, optimum and maximum soil temperatures for seed germination are 18, 35 and 38°C, respectively. Germination is slow and erratic when soil temperature is below 20°C. Fruit maturing when daily mean air temperatures are below 21°C have poorer quality. Pumpkins do well in hot weather, but very high temperatures (43-46°C) can cause temporary vine wilting, sunburned fruit, and soft fruit at harvest with reduced shelf life. The spacing depends on whether cultivars are bush or vining. Large fruited pumpkins are often planted in hills 1.8 to 2.4 m apart with rows 1.8 to 2.4 m apart also. Large acreages can be seeded in rows 1.8 to 3 m apart. Seeds are placed at 5 to 10 cm deep. In-row spacings of 15 cm are common and plants may be thinned to a final spacing at the 2- to 4-leaf stage. Fruit size may be modified by plant spacing. *Closer spacings generally produce smaller fruit and wider spacings generally result in larger fruit.* The number of mature fruits harvested per plant is usually low, and the weight of individual fruits varies widely from 0.5-10 kg, depending on species and cultivar. Under low input conditions, the yield is around 5 t/ha; with good care, a yield of 15 t/ha is reasonable. With improved hybrid cultivars a yield of over 30 t/ha can be attained. An average yield of leaves is 2 t/ha per

picking, or about 20 t/ha during a harvest period of two months (Grubben and Chigumira Ngwerume, 2004). Growing under trellis system has been proven to give better yields than the open ground system. Preliminary studies carried out in Tanzania with *Curcubita moschata* sp. have shown that fruit yields of 10.6 t/ha can be realized under trellis system compared to 7.2 t/ha under open ground cultivation (Figures 53 and 54; Oluoch et al., 2009). The traditional cropping system of pumpkin for leaves and/or fruit production is open ground intercropping in maize or sorghum fields. It is also planted on termite hills, fertile patches of abandoned homesteads and kraals (Grubben and Chigumira Ngwerume, 2004). Mono-cropping is the appropriate system for commercial pumpkin production of improved cultivars, but in African countries this is still rare. To maximize land use under a pumpkin farming system, the trellis production system should be adopted with other crops planted in between the rows.

**Figure 53: Growing pumpkins under trellis system, Arusha, Tanzania**

**Figure 54: Growing pumpkins under open ground system, Arusha, Tanzania**

### Irrigation

Pumpkins have extensive, moderately deep root systems that efficiently explore the soil for water. Preplant or post-plant irrigations should be applied to ensure seed germination, emergence and stand establishment. After marketing, irrigation is the second most important element of a successful vegetable production system. Sprinkler irrigation is frequently used during stand establishment, but this is not a good system once the vine canopy has become large, because it may result in significant vine and fruit disease. Furrow irrigation is the least efficient, least uniform, but is a common method of irrigation. In pumpkin, the most critical period for irrigation is while fruits are developing. In pumpkin, fruit size and yield are severely reduced by moisture stress. Any stress related to lack of water during fruit sizing can lead to the development of blossom-end rot.

## Mulching

Using grass or polyethylene (plastic) mulch offers growers several advantages. Plastic mulch increases the soil temperature, accelerating plant growth and development. It also conserves soil moisture and reduces several common problems, such as soil compaction and crusting, fruit rot on the ground, fertilizer leaching, drowning of crops, evaporation, and competition from weeds. Although using mulch will increase production costs, those costs are offset by increased profits from earlier and larger yields of high quality produce. Drip irrigation systems are recommended for use with plastic mulch.

## Weeding

For better weed control, select locations with low weed populations or no perennial weed problems. Use mechanical weed cultivation between rows, and employ practices which encourage rapid growth and development so as to fasten the process of developing a canopy. Consider using polyethylene or grass mulch as part of your weed control strategy.

## Flowering and pollination

Pumpkin plants produce separate (male) flowers and female flowers on the same plant. This sex expression is called monoecious. Both kinds of flowers are open for only one day and in the morning. Male flowers drop off the plant the day after closing, but fruiting flowers remain attached for several days. If pollination is successful, the fruiting flowers will begin to enlarge. Most vines of large fruited cultivars can only support 2 or 3 developing fruit at a time and later developing flowers will not set fruit. Small fruited cultivars can support many more. *The only effective pollinators are bees*. Environmental and disease factors can significantly influence flowering, pollination and fruit set. Plants under stress will have fewer flowers and will not set as many fruit as healthy plants. Cucurbit crops are highly dependent on active pollination by bees. Not only does adequate pollination increase yield, but good pollination may improve the earliness and quality of the crop. Because pollen is borne on male flowers, bees are essential to transfer pollen to female flowers. Cucurbit pollen is not effectively moved by wind. Fruit size and seed set of cucurbits are strongly related to bee activity. Because of the large size of the flowers and pollen, the small honey bees do not pollinate squash as efficiently as larger native bees. The pollination requirement of pumpkin is one bee per ten “female” flowers which is considered the minimum level of activity to maximize fruit yield. A minimum of two honey bee hives per hectare is sufficient to achieve a good level of bee activity. Yield increases have been achieved with up to six hives per hectare.

Several factors play a significant role in managing bees for effective pollination. Among these, weather is one of the most important. Bees are less likely to forage for nectar and pollen during poor weather. Rain, strong winds and high or low temperature extremes also will reduce bee activity and consequently reduce yields. If poor pollinating conditions exist during the flowering period, additional bee hives (Figure 55) may have to be supplied. A second factor in managing bees for pollination is the presence of “competing blooms” during the flowering period. Most cucurbit flowers are poor sources of nectar and pollen. They may be less attractive to bees than nearby flowering weeds or other crops. In such cases, crops that may attract bees away from the pumpkins during the flowering period should not be planted nearby (at least a 750 m buffer is desirable). Similarly, weeds adjacent to the crop that may serve as competing blooms before the pumpkins begin to bloom should be destroyed. The use of domesticated honeybees (Figure 55) is the most effective means to pollinate cucurbit crops. However, wild bees or feral honeybees can be extremely important as pollinators. Wild bees include several species of native, ground-nesting bees that prefer pollen and nectar from specific cucurbits; although they are less dependable than domesticated bees.

**Figure 55: Bee hives to help with pollination of vegetable crops, Nairobi, Kenya**

## HARVESTING AND STORAGE

The leaves of pumpkin are highly perishable. When grown for sale at local markets, leaves are tied in bundles and these are kept moist until sold. Leaves are sometimes stored and marketed in dried form. To dry the leaves, they are chopped into small pieces and spread in the sun to dry for 2-3 days depending on weather conditions (Grubben and Chigumira Ngwerume, 2004). The dried leaves are stored in containers and are either marketed in some communities or used during the dry season. For fruits, pumpkins should be harvested after the skin has hardened and cannot be penetrated with a fingernail**.** Pumpkin fruits are still physiologically alive even after they have matured and are removed from the vine. They need to be cured before storage. The objective of curing and storage is to prolong the post-harvest life of the fruit. Mature fruit store better than immature fruit. When mature, pumpkins have hard skins that resist puncture with your thumbnail. Skins of mature fruits appear dull and dry compared to the fresh, bright sheen of the skin of immature fruit. Leave a long stem (handle) on pumpkins (Figure 56). On squashes, the stems are removed completely. To lessen confusion, dead vines do not indicate maturity in pumpkin and squash. When vines die prematurely from disease or drought, for example, the fruits are likely immature and will not store for long. Curing involves elevating storage temperatures to 24-30°C with 75-80% relative humidity for about 5-10 days. Curing heals wounds, helps ripen immature fruit, enhances color, and ensures a longer post-harvest life. After curing, the temperature and relative humidity should be reduced to 10-13°C and 50-75%, respectively. Pumpkin and squash are chilling sensitive and should not be stored below 10°C.

**Figure 56: Pumpkins being commercialized in a supermarket in Nairobi, Kenya**

**DISEASES**

The most common diseases of pumpkin are: damping -off (seedling disease), viruses (stunt growth and alter the appearance of the fruit rendering it unsaleable), angular leaf spot, bacterial leaf spot, downy mildew, powdery mildew, scab, black rot, and Phytophthora blight.

To control most of these diseases, plant resistant varieties when available. Where resistant varieties are not an option, use fungicides, insecticides, weed control and good sanitation practices.

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# Managing Diseases and Pests of Indigenous Vegetables for GAP Compliance in Sub-Saharan Africa

**Mathew M. Abang[1], Agnes W. Kihurani[2] and R. Srinivasan[3]**

[1]*Vegetable Breeding and Seed Systems Program, AVRDC-The World Vegetable Center, Regional Center for Africa, P.O. Box 10, Duluti, Arusha, Tanzania*
[2]*Horticulture Department, Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya*
[3]*Entomology Unit, AVRDC-The World Vegetable Center, P.O. Box 42, Shanhua, Tainan 74151, Taiwan, ROC (srini.ramasamy@worldveg.org, Phone: +886 6 583 7801 ext. 426)*

**Abstract**

Indigenous vegetables play a key role in human nutrition, food security, and poverty reduction for the rural and urban poor in sub-Saharan Africa. Increasing demand for vegetables such as amaranth, African nightshade, and Ethiopian mustard coupled with finite agricultural resources threaten the sustainability and profitability of production. Pests and diseases reduce yields, and harmful pesticide regimes pose major risks to human and environmental health. Despite the importance of indigenous vegetables, there has been little research into the diagnosis, epidemiology, and sustainable management of the major pests and diseases of these species. Nevertheless, progress has been made recently in germplasm enhancement, improved soil health and water quality, reduced microbial contamination of vegetables, and integrated pest management. AVRDC-The World Vegetable Center, in collaboration with private and public sector partners, is leading efforts to reduce malnutrition and poverty in the region through the development of good agricultural practice (GAP)-compliant technologies that contribute to the production of safe and nutritious vegetables. Strategies include improved knowledge of the diseases and insect pests affecting indigenous vegetables, planting varieties resistant to major pests and diseases, and cultivation practices that reduce indiscriminate and excessive use of fertilizers and pesticides. This paper reviews our current understanding of the nature and management of diseases and pests of indigenous vegetables and highlights opportunities with biological alternatives that reduce harmful pesticide regimes, protect the production environment and the produce, remove barriers to trade, and improve human health in sub-Saharan Africa.

## FOOD SAFETY AND THE NEED FOR GAP COMPLIANCE IN PEST AND DISEASE MANAGEMENT

Repeated and well-publicized food crises in Europe and the United States of America (Tables 37 and 38) (Champseix et al., undated; Champseix and Julien, undated) have made food safety a matter of global concern and consumers have become more wary of the food supply. To preserve consumer health, international standards comprising more integrated activities in production, transformation, and distribution have been put in place and enforced, and suppliers need to comply to ensure survival in the market (Engels, 2005). Further, it has been established that non-compliance with set standards, at given points along the production chain is responsible for the increasing rate of food poisoning (Samb and Schiffers, undated).

**Table 37: Repeated food crises in Europe**

| Year | Food crisis |
|---|---|
| 1969 | Brucellosis of cattle |
| 1984 | Contaminated blood |
| 1997 | Mad cow disease |
| 1999 | Listeria, dioxin fungicides on pallets |
| 2001 | Foot-and-mouth disease |
| 2004 | Bird flu |
| 2006 | Blue tongue (Cattle fever) |
| 2008 | Melamine (China) |

**Table 38: Recent food safety issues in USA**

| Year | Produce safety issues |
|---|---|
| 2000, 01 & 02 | Melons Cantaloupe: Salmonella, 2 deaths |
| 2002 | Romaine lettuce: E. coli, 27 cases |
| 2002 | Tomatoes: Salmonella, 512 cases |
| 2003 | Spinach: E. coli, 32 cases/2 deaths |
| 2003 | Green onions: Hepatitis A, 500 ill/4 deaths |
| 2004 | Tomatoes: Salmonella, 60 cases |

When national authorities are confronted by a food crisis, the following challenges arise:

- Impossible to estimate the risk of exposure for the national population
- Difficult to clearly identify the hazard origin (lack of traceability)
- Impossible to choose effective control measures
- Authorities usually respond with greater controls

Consumers need safe food; food products should not cause health problems or death. Food quality should translate to customer satisfaction; producers and distributors must take responsibility to assure quality. This is the reason for the evolution toward international crop protection standards.

Food quality has many facets:

- *Service:* preservation, storage, consumer info
- *Regulatory*: product and environmental safety
- *Nutritional*: quantity and quality
- *Organoleptic*: appearance, taste
- *Sanitary and toxicological*: no foreign bodies, no insects, no dangerous microorganisms, no toxins, no pesticides residues, etc.

Good agricultural practices (GAP) is a collection of principles to apply for on-farm production and post-production processes, resulting in safe and healthy food and non-food agricultural products, while taking into account economical, social and environmental sustainability. This means that producers must identify all aspects of their activities which determine the safety of their products (Samb and Schiffers, undated). GLOBALGAP sets voluntary standards for the certification of agricultural products around the globe and EUROPGAP (European Retailer Produce Working Group on Good Agricultural Practices) is

an example of a quality protocol that establishes the minimum standard for major retailers in Europe.

GAP in the use of pesticides includes the nationally authorized safe uses of pesticides under actual conditions necessary for effective pest control, and which leaves a residue which is the smallest amount practicable (Mushobozi, 2010). In order to remain competitive, it is imperative that vegetable producers in sub-Saharan Africa develop quality control systems to guarantee product safety as a way of responding to a constantly changing environment because of the internationalization of markets (Engels, 2005). For instance, okra is one of sub-Saharan Africa's agricultural export commodities to the European Union (EU) that is subjected to stringent EU and EUREPGAP regulations, maximum pesticide residue limits, food safety, and traceability of the produce from the field to the exporter.

Primary production should ensure that the foodstuffs are wholesome and suitable for their intended use. If possible, it is important to avoid production in areas where the environment constitutes a threat to food safety; take the necessary steps to control contaminants, pests, and animal diseases; and adopt practices and measures designed to ensure the food is produced in sufficiently hygienic conditions. The justification for these recommendations is to reduce chances that carelessness can jeopardize food safety or make food less fit for human consumption at later stages in the food chain.

## REGULATIONS ON PESTICIDE RESIDUES AND COMPLIANCE WITH MRLS

Plants suffer from pests, diseases, and competition from weeds and thus require protection, often through the use of chemical pesticides. Small amounts of these pesticides and residues may turn up in food supplies. In response to growing pressure from consumers and environmental protection groups, the permitted levels of pesticide residue in food have been set by national regulatory authorities and are controlled by law. These levels are called "Maximum Residue Levels" (MRLs). They have been set at a point where human health is unlikely to be at risk, with wide safety margins above the normal dietary intake of the food product. It is important to note that the set MRLs are unlikely to be exceeded if the pesticide is used as directed, according to the product label instructions and the relevant code of practice (Agromisa Foundation, 2004).

## RELATIONSHIP BETWEEN INTEGRATED PEST MANAGEMENT (IPM) AND GOOD AGRICULTURAL PRACTICE (GAP) IN INDIGENOUS VEGETABLE PRODUCTION SYSTEMS IN SUB-SAHARAN AFRICA

Integrated pest management (IPM) is defined as a concept for plant protection which makes use of all acceptable economic, ecological, and toxicological methods for keeping the numbers of destructive organisms below the economic damage threshold, whereby the purposeful use of natural regulatory factors is of primary importance (Schwab, 1995b). It is regarded as a purpose-oriented use of pesticides, applications being determined by the intensity of pest infestation. Its objective is to reduce excessive reliance on pesticides that threatens production, sustainability, human health and the environment and calls upon producers to diversify pest control practices with an emphasis on non-chemical methods such as biological control, host-plant resistance, cultural control, physical control, mechanical control, and legislative control. In IPM pesticides become just one tool, among several others, and they are used with care only when absolutely necessary to minimize their adverse effects on beneficial organisms, humans, and the environment. Producers select the methods used in an IPM strategy on the basis of cost, level of technology, type of crop, availability of pesticides, and other environmental and social considerations.

Today, a significant share of vegetable crops are produced under contract with agri-food companies which impose specifications requiring producers to make reasonable use of plant

protection products or even apply IPM practices. For example, the EUROPEGAP protocol that deals with crop protection encourages producers to use only “selected products that are specific to the target pest, weed or disease and which have minimal effect on populations of beneficial organisms” (Schiffers and Moreira, undated).

The reason for great caution in the use of pesticides is that despite their usefulness, pesticides are composed of biologically active substances and may damage more than just the organisms or plants they were designed to destroy or control. Their use poses numerous problems for the health of workers, consumers, and the environment, especially in sub-Saharan African countries where there is low average level of applicator skill. The adverse effects of pesticides are exacerbated by poverty and the prevalent climatic conditions (Jager, 1995). The effects of pesticide poisoning occur more quickly in the tropics and subtropics than in temperate regions of the world because the human body tends to absorb toxic substances faster in hot temperatures. Protective clothing is also often absent due to poverty and sometimes is not used because the tropical heat makes it uncomfortable to wear. A Pesticide Action Network (PAN) study found that most farmers do not use appropriate equipment or protective measures: in Senegal, only 14% of vegetable farmers use protective clothing when spraying insecticides (PAN, 2007). Up to 20% of vegetable farmers in the country had witnessed or heard of cases of pesticide poisoning. In Benin, 43% of vegetable farmers interviewed reported that the effect of pesticides on their health was considerable or noticeable.

Pesticide residues are foreign matter in agricultural produce and therefore undesirable. They should be absent or only be present in insignificant amounts. A total absence of residues is not always possible, but with good agricultural practice the total amount of residue per unit can be kept below the minimum residue level set by law. Observance of preharvest interval (PHI) ensures that the pesticide sprayed on an agricultural produce has sufficiently broken down and has been reduced to negligible amounts. The recommended PHIs for pesticides may range from three days to three weeks, depending on the chemical and physical properties of the product (Agromisa Foundation, 2004). Many farmers fail to observe PHIs, sometimes due to ignorance, but sometimes to avoid any loss of income (Schwab, 1995a).

The following main problems arising from the use of pesticides have been cited (Schiffers, unpublished information) and need to be addressed in ensuring that good agricultural practice is maintained in vegetable production:

- Easy access by small farming operations to inappropriate pesticides (highly toxic chemicals, unsuitable packaging among others)
- Farmers’ ignorance of the hazards involved in handling the products
- Lack of adequate protective clothing or equipment for application
- Absence of labels with instructions on how to handle, use, and dispose of the product
- Use of persistent pesticides inappropriate for food crops
- Noncompliance with minimum interval between the last pesticide application and harvesting (residues)
- Reuse of empty pesticide packaging to hold food or water
- Improper repackaging of pesticides by unauthorised retailers
- Lack of facilities for storing pesticides
- Lack of facilities designated for the disposal of expired pesticides
- Insufficient medical knowledge to treat victims of chemical intoxication

Pesticides can be applied without presenting a health hazard if the operator acts carefully, uses the recommended means of protection, and follows the safety precautions given on each product label.

## DISEASE AND PEST MANAGEMENT IN SELECTED INDIGENOUS VEGETABLES

### African eggplant (*Solanum aethiopicum* L. and *S. macrocarpon* L.)

The edible African eggplant (*S. aethiopicum*) has three groups: Gilo (fruiting type), Shum (leafy type), and Kumba (leafy type). *S. macrocarpon* is a closely related fruiting type. Spider mites are the predominant pest on African eggplant. However, the fruit and shoot borer, which infests eggplant (*S. melongena*) in Asia, also occurs on African eggplant in some African countries.

#### *Diseases*

Eggplant is affected by most diseases commonly associated with solanaceous crops. Diseases attack the crop at all growth stages (Chen and Li, 2009). Only the most common diseases are mentioned here with their possible control measures.

*Damping off (Pythium spp., Phytophthora spp., Rhizoctonia spp.)*

The fungus attack usually starts on the germinating seed, spreading to the hypocotyl, basal stem, and developing tap root. The affected seedlings are pale green, and a brownish lesion is found at the basal portion of the stem that girdles the stem. The affected tissue rots and the seedling collapses. The disease is soil-borne. The disease may be controlled by soil sterilization and seed treatment with fungicides or hot water.

*Phomopsis blight (Phomopsis vexans)*

Phomopsis blight or fruit rot is probably the most serious and widespread eggplant disease (Figure 57). It occurs in the stems, leaves, and fruits. The fungus attacks the stems of the young plants at the soil line, often girdles the stem and causes the plant to break off, wilt, or die. The fungus also attacks the stems of older plants at any point, causing sunken, oval, dark-brown cankers. Leaf infection first appears as round, brown spots; the centers of the spots later turn gray. Fruit spots are pale and sunken. The spots frequently originate on the calyx and expand into the fruit pedicel and then into the fruit. Fruit decay is soft and spongy and may penetrate rapidly throughout the fruit. To control this disease, use clean seed, as the fungus may be carried on the seed; adopt a three- to four-year crop rotation; use resistant varieties; scout for presence of disease and spray with a recommended fungicide while adhering to instructions on the label.

**Figure 57: Severe Phomopsis blight of African eggplant**

*Leaf spot (Alternaria spp., Cercospora spp.)*

There are four different types of leaf spot in eggplant caused by *A. melongenae*, *A. solani*, *C. solani-melongenae*, and *C. solani*. The Alternaria leaf spots produce the characteristic leaf spots with concentric rings. The spots are mostly irregular, 4-8 mm in diameter and may enlarge and cover a large area of the leaf blade. The leaves may drop off due to severe infection. The Cercospora leaf spots are characteristically chlorotic lesions, angular to irregular in shape, and later turn grayish brown with profuse sporulation at the center of the spot. Severely infected leaves drop off prematurely resulting in reduced yield. The leaf spot disease may be primarily controlled by maintaining proper field sanitation. The general control measures suggested for Phomopsis blight, if followed, are also effective for leaf spots.

*Verticillium wilt (Verticillium dahliae, V. albo-atrum)*

The most characteristic symptoms of Verticillium wilt are found on the stems and roots. The infected plants become stunted in growth and generally, do not flower and set fruit. If the infection takes place after flowering or fruit setting, the flowers and fruits are deformed, flaccid, and finally drop off. A lengthwise cut of the infected stem shows dark-brown discoloration in the vascular tissue. The affected leaves turn yellow and then brown between veins followed by wilting and dropping off. After the plant is thoroughly invaded, the roots and the base of the stem may decay. The pathogen is soil-borne and the primary inoculum usually comes from the soil. Soil sterilization and crop rotation in which crops other than potatoes, tomatoes, and peppers are grown are recommended as control measures. Using resistant varieties and grafting eggplants on suitable rootstocks also are effective methods to reduce the disease severity.

*Fusarium wilt (Fusarium oxysporum f. sp. melongenae)*

Fusarium wilt (Figure 58) induces symptoms that begin as slight vein clearing on outer leaflets and drooping of leaf petioles. Later the lower leaves wilt, turn yellow and die and the entire plant may be killed, often before the plant reaches maturity. In many cases a single shoot wilts before the rest of the plant shows symptoms or one side of the plant is affected first. Because *F. oxysporum* and *Verticillium* spp. fungi are widespread and persist several years in soil, a long crop rotation (4 to 6 years) is necessary to reduce populations of these fungi. The rotations should not include any solanaceous crop, e.g potato, tomato, pepper, or eggplant (Chen and Li, 2009). Removal and destruction of infested crop debris, reduction of irrigation frequency and amount of water, proper drainage of fields, disinfection of pruning tools, maintenance of high level of plant vigor with appropriate fertilization, adequate irrigation, soil fumigation, and soil solarization are important means to control the pathogens. Resistant germplasm has been identified at AVRDC.

**Figure 58: Fusarium wilt of African eggplant**

*Bacterial wilt (Ralstonia solanacearum)*

Bacterial wilt disease causes a severe problem in eggplant cultivation in the subtropics and tropics. Once it is well established, it can be one of the most destructive pathogens known. The symptoms of bacterial wilt on susceptible plants are yellowing, curling and wilting of leaves, disintegration of stem and roots, and death. When newly infected stems or roots are cut transversely and left for a short time or are pressed strongly, a dingy gray to yellowish ooze appears from the darkened circle. Crop rotations with immune species, eradication of weeds, good drainage, growing healthy seedlings, and grafting plants on suitable resistant rootstocks are important control measures.

*Viruses*

Several viruses infect eggplant under natural conditions and produce mosaic symptoms. They include *Chili veinal mottle virus*, *Cucumber mosaic virus* (CMV), *Pepper veinal mottle virus*, *Potato virus Y* (PVY), *Potato virus X* (PVX), and *Tobacco ringspot virus* (TRSV) (Nono-Womdim, 2001; Nono-Womdim et al., 2001). Plants infected with a virus are generally stunted in growth and show mosaic symptoms on leaves (Figure 59). Chen et al. (2001) described a severe mosaic disease of *S. macrocarpon* from Cameroon characterized by systemic mosaic on leaves and fruits, leaf mottling and crinkling, fruit necrosis, and stunting of plants. Two viruses – *Eggplant mottle crinkle virus* and *Tobacco mosaic virus* (TMV) – were found to be associated with the symptoms.

**Figure 59: Virus symptoms on African eggplant**

**Virus disease management:** Eggplant is much less susceptible to viruses than tomato and capsicums, and virus diseases are generally of minor importance. If necessary, the eggplant should not be planted near sources of virus inoculum such as pepper, tobacco, tomato, and cucumber. Plant disease-free seedlings, uproot diseased plants, and protect fields and nurseries from insect vectors such as aphids. Using sticky yellow polythene sheets erected vertically on the windward side of fields and nurseries can help trap these vectors; the aphids are attracted to the yellow color and are caught on the sticky polythene.

***Pests***

*Spider mite, Tetranychus sp. (Acarina: Tetranychidae)*

Spider mite infests several African indigenous vegetable crops including African eggplant. *T. evansi* is the most predominant species in Africa. Spider mites usually extract the cell contents from the leaves using their long, needle-like mouthparts, which results in reduced

chlorophyll content in the leaves, leading to the formation of white or yellow speckles on the leaves (Figure 60).

**Figure 60: Spider mite symptoms on African eggplant**

In severe infestations, leaves will completely desiccate and drop off. The mites also produce webbing on the leaf surfaces in severe conditions. The spider mite is minute in size, and varies in color.

Management practices include (i) predatory mites such as *Phytoseiulus persimilis* Athias-Henriot, *Phytoseiulus longipes* Evans, *Amblyseius womersleyi* Schicha, and *A. fallacies* Garman, which are more effective under protective structures and in high humidity conditions; (ii) predatory mites and pathogenic fungi such as *Neozygites floridana*, *Beauveria bassiana*, and *Metarhizium anisopliae*, which act synergistically and reduce the population density of spider mites significantly (Wekesa et al., 2005, 2007; Furtado et al., 2007); and (iii) use of resistant or moderately resistant cultivars available in the region. For instance, *S. aethiopicum* ssp. Gilo accessions such as Bot 10 c and Bot 10 e were significantly less damaged by spider mites (Seck, 2000).

*Fruit and shoot borer (FSB), Leucinodes orbonalis (Lepidoptera: Pyralidae)*

FSB occurs in several countries in Africa such as Ethiopia, Ghana, Kenya, Mozambique, Nigeria, South Africa, Tanzania, Uganda, and Zimbabwe (Choudhary and Gaur, 2009). It is a major pest on *S. macrocarpon* in Cameroon (Fontem et al., 2003).

The larva starts boring near the growing point or into the flower buds or fruits. During the early vegetative phase of the crop growth, it feeds inside the tender shoots, resulting in wilting of young shoots, followed by drying and drop-off. During the early reproductive phase, the larva occasionally feeds on flower buds and flowers. However, it prefers to feed on the fruits. Damaged fruit exhibits boreholes on the surface, which often are sealed with excreta. The larva feeding inside the fruit creates tunnels filled with frass and fecal pellets.

The larva is pink with sparse hairs on the warts on the body and a dark brown or blackish head (Figure 61).

The adult moth is white or dirty white with pale brown or black spots on the dorsum of thorax and abdomen (Figure 62).

Wings are white with a pink or blue tinge, and have pink or brown and red spots on the forewings.

**Figure 61: *Leucinodes orbonalis* larva**

**Figure 62: *Leucinodes orbonalis* adult**

Management practices include using resistant or moderately resistant cultivars available in the region – *S. aethiopicum* accessions such as Cherry, Africa 4, and Tengeru were significantly less damaged by *L. orbonalis* (AVRDC, 2003a); (ii) promptly remove and destroy infested shoots and fruit at regular intervals until final harvest; and (iii) install sex pheromone lures in traps either at canopy level or slightly above the canopy level for effective attraction of adult moths.

*Nematodes [Root-knot nematodes (Meloidogyne spp.)]*

Eggplant is highly susceptible to the nematode. Attacked plants become stunted, growth is reduced, and leaves show yellowing or chlorotic symptoms. The infestation is also easily recognized by the characteristic root galls. Proper crop rotation with other crops resistant to root-knot nematodes such as marigold will help reduce nematode populations. Recommended nematicides may be used for controlling the root-knot nematodes, but it is important to adhere strictly to label instructions.

**African nightshade (*Solanum scabrum* Miller)**

Broad-leafed African nightshade (*S. scabrum*) is one of the most promising leafy vegetables among vegetable nightshade species. Its leaf production is higher than those of narrow-leafed species like *S. villosum* and *S. eldoretianum* (Schippers, 2000).

***Diseases***

*Damping-off*

Seedling disease (= *Pythium* sp.) causes young seedlings to either fail to emerge, or die soon after emerging or after transplanting. The disease can be particularly devastating under cool, perpetually wet conditions. *Rhizoctonia* sp. also causes damping-off in nightshades. Management of this disease is similar to the management of damping-off in African eggplant.

**Figure 63: Damping-off symptoms on African nightshade**

*Early blight (Alternaria solani)*

This is a potentially serious foliage disease in warm humid weather. Leaves develop black lesions that progressively develop into concentric rings in a bulls-eye pattern. Tissue surrounding the lesions may turn yellow and leaves eventually fall off. This fungus is also reported to cause collar rot (a form of damping-off) in nightshade seedlings.

**Management:** Use fungicide treated seed and disease-free transplants. Minimize plant injury in transplants by controlling insects and by avoiding sandy soils. Avoid extended periods of leaf wetness on plants. Avoid dense plant populations in fields to allow for good ventilation between plants. Use furrow or drip irrigation rather than overhead irrigation. If overhead irrigation is used, irrigate in the late morning to allow the plants to dry before evening. Use a three or four-year rotation with non-solanaceous crops. If possible, remove diseased plants or destroy them immediately after harvest. Alternatively, bury diseased crop debris by deep-plowing to reduce spore levels available for infection of new plants. Avoid planting overlapping nightshade crops in adjacent areas. Maintain vigorous plant growth. Broad-spectrum fungicides are available for control of the disease, if necessary. Control of late onset of the disease may not be required. Contact your local extension specialist for recommendations.

*Late blight (Phytophthora infestans)*

This is a major disease of nightshade (Fontem et al., 2005), which causes a grayish-green rot of leaves, eventually causing them to brown and shrivel (Figure 64). The fungus becomes problematic in very wet and cool weather conditions, particularly if plants are closely spaced. If not controlled, late blight can cause complete defoliation of a crop within a relatively short period of time.

**Figure 64: Late blight on African nightshade**

**Management:** Reduce the amount of initial inoculum or suppress the rate of disease development through the use of disease-free seedlings. Remove and destroy blighted nightshade plants. Reduce leaf wetness by staking tomatoes and using drip irrigation. If drip irrigation is not available, reduce the number of furrow irrigations to a minimum or use sprinkler irrigation in the morning or midday to prevent the foliage from being wet overnight. Avoid over-fertilization of nitrogen. Spores of *P. infestans* can be dispersed aerially over long distances; therefore, all tomato growers in the production region need to collaborate to eliminate sources of inoculum. If this doesn't happen, a few fields with infected plants can affect production over a much larger region. Use varieties that are less susceptible to *P. infestans*. Check plants carefully for the first incidence of the disease, particularly after extended periods of leaf wetness and moderate temperatures. Apply fungicides as soon as possible at the first sign of the disease or ideally before symptoms develop. Both protectant and systemic fungicides will likely be necessary. Rotate with a broad-spectrum protective fungicide. It is advisable to check with local extension agents for recommended varieties and fungicides.

*Fusarium wilt (Fusarium oxysporum)*

The initial symptoms include drooping and wilting of lower leaves, followed by loss of green color, and eventual wilting and death of the whole plant (Figure 65). Characteristically, leaves on only one side of the stem turn yellow first and stems do not show soft rot symptoms. When the stem is cut lengthwise, a dark brown discoloration of the woody water-conducting tissues is observed. Development of this disease is favored by warm humid weather. Management of the disease is similar to that for Fusarium wilt of eggplant.

**Figure 65: Fusarium wilt of African nightshade**

*Verticillium wilt (Verticillium dahliae)*

This infection results in the yellowing of older leaves, followed by wilting of the growing tips and shoots during the day when temperatures are high. As the disease progresses, leaves wither and eventually drop. When the stem is cut lengthwise, the base shows a discoloration of the woody tissue similar to Fusarium wilt, but is usually darker, and generally it occurs only in the lower part of the stem. Disease development is favored by cool temperatures and wet conditions. Management of the disease is similar to that for Verticillium wilt of eggplant.

*Bacterial wilt (Ralstonia solanacearum)*

This is characterized by a rapid wilt of the plant while the leaves initially remain green. If the stem is cut cross-wise, it appears brown and tiny drops of yellowish ooze may be observed. Disease development is favored by high temperatures and a lot of moisture.

**Management:** Control of wilt diseases of African nightshade is very similar to the management of these diseases in African eggplant. The integration of crop rotation with immune species, good farm sanitation, use of healthy seedlings, and good drainage is particularly effective. *S. scabrum* tends to be more susceptible to wilting than *S. nigrum*.

*Leaf mold (Cladosporium oxysporum)*

This fungus causes pale green to yellowish spots on the upper leaf surface, and a grayish-green velvety mold on the lower leaf surface. Eye spot (*Cercospora nigrescens*) causes light-gray to black spots surrounded by yellowing tissue on the upper leaf surface. Severely infected leaves continue to yellow and eventually drop. Southern blight (*Sclerotium rolfsii*) causes the development of a brown dry rot lesion near the soil line which progresses rapidly to girdle the stem, followed by the eventual wilting of above-ground parts (Figure 66). These diseases are generally of minor importance and management practices for the control of the major diseases will lead to significant reduction of these diseases.

**Figure 66: Sclerotium stem rot of African nightshade**

*Viruses*

Viruses including leaf curl, leaf mosaic, and yellow vein viruses have been observed to infect nightshades. Viral symptoms include light and dark green mottling of leaves, yellow or purple veins, malformation of leaves and stunting (Figure 67). *Tomato mosaic virus* (ToMV) is one of the viruses found on African nightshade throughout sub-Saharan Africa (Nono-Womdim, 2001; Nono-Womdim et al., 2001). Viruses are readily transmitted by any means that introduces even minute amounts of sap from infected to healthy plants, including sucking

insects (aphids, white flies) as well as inadvertently bruising young leaves by touching them. Disease management is the same as for African eggplant.

**Figure 67: A severely stunted virus-infected plant (note how plant height compares with 15 cm pencil)**

***Pests***

*Aphids, Aphis spp. (Homoptera: Aphididae)*

Aphids such as the black aphid (*Aphis fabae*) suck the plant sap, leading to curled and wrinkled leaves, which makes them unmarketable (AVRDC, 2003b). Feeding aphids cause general weakening of the plants and stunted growth. With severe infestations during the early stages of plant growth, the entire plant dies. Aphids, like all sucking insects, have the potential to transmit viruses.

Aphids are small, soft-bodied, pear-shaped insects. They possess small tubes (tubercles) arising from either side of the back of their abdomen.

The management practices include (i) crop rotation with other crops; (ii) monitor the crop at regular intervals; (iii) cover the plots with a fine screen or nylon mesh netting (32-mesh or finer); (iv) conserve natural enemies such as predatory ladybird beetles and syrphid flies, as well as parasitoids; and (v) spraying of botanical pesticides such as neem at the rate of 3-5%.

*Spider mite, Tetranychus evansi Baker and Pritchard (Acarina: Tetranychidae)*

Due to sap sucking, *T. evansi* causes similar damage symptoms on African eggplant and African nightshade – the formation of white or yellow speckles on the leaves (Figures 68 and 69) due to sap sucking. The mites also produce webbing on the leaf surfaces. In severe infestations, leaves become speckled, covered with pale yellow dots giving a dusty appearance, and eventually dry up and drop off. Mites multiply rapidly in dry hot weather, when they can cause the crop to fail prematurely due to extensive defoliation.

The spider mite is minute in size, and males are smaller than females. The female is oval shaped whereas the male is an elongated, triangular shape. Mites vary in color, from orange to dark red or even brown. Hence, they are also called red spider mites.

Management practices include (i) use of predatory mites such as *P. persimilis* with pathogenic fungi such as *N. floridana*, which reduces the population density of spider mites significantly on African nightshade (Duarte et al., 2009); and (ii) conservation of predators such as *A. womersleyi* and *A. longispinosus* (Ho, 2006).

**Figure 68: Spider mite on African nightshade**

**Figure 69: Extensive defoliation of nightshade by spider mites**

Other pests of nightshades include:

- Red and black ants and cutworms. These can be a problem for newly transplanted seedlings, particularly when the field contains a lot of undecomposed plant debris. Ants de-bark the plants just below the soil surface, causing them to wilt and die, while cutworms truncate the trunk just below the soil surface. It is easy to confuse wilt symptoms due to ants and cutworms with *Fusarium* or *Verticillium* wilt, but digging up the soil 1 cm around the base of the plant will reveal if wilting is due to de-barking by ants or some other cause.
- Caterpillars (larvae) and grasshoppers (*Zonocerus variegatus*) that chew away the leaves, reducing yield and making leaves less marketable.
- White flies (*Bemisia tabaci*) suck plant sap, making plants weak and stunted. Like aphids, they are also prime agents for transmitting viruses from infected to healthy plants.
- Beetles, including *Epilachna hirta*, *Lagria* sp., and *Podagrica* sp. all chew the leaves, poking holes in them and making them less attractive.
- Nematodes affect the root systems of plants, making them stunted and discolored, and eventually causing the plant to wilt and die. Root knot nematodes (*Melodigyne* sp.)

can be particularly troublesome in hot dry weather. Symptoms include a shallow root system with some dead (sometimes visibly truncated) roots and excessively fibrous areas.

**Amaranth (*Amaranthus* spp.)**

Although amaranth has several species (such as *Amaranthus hybridus* L., *A. thunbergii* Moq.), *A. blitum* L. and *A. cruentus* L. are the major species grown in Africa.

Pests and diseases can be important problems with amaranth production. This is contrary to the view that this indigenous vegetable is hardly affected by pest or disease problems. *A. tricolor* is considered more susceptible to pests and diseases than *A. cruentus.*

***Diseases***

*Damping-off (Pythium aphanidermatum, Rhizoctonia solani and Aphanomyces sp.)*

Seeds may rot in the soil before emergence (pre-emergence damping-off). Seedlings may exhibit stem canker above the soil line and/or root necrosis. Affected seedlings eventually wilt (post-emergence damping-off). Use disease-free seeds, and avoid overwatering and dense planting.

*Wet rot of stems and leaves (Choanephora cucurbitarium)*

Affected plant parts have hairy appearance (silk-like threads) consisting of fungal spores. The disease can cause heavy defoliation during rainy season. Stem and root rot can contribute to lodging late in the season if soils are wet. At the National Horticultural Research Institute in Nigeria, many amaranth lines have failed due to wet rot of leaves and young stalks caused by *C. cucurbitarium*. Similar observations have been made in Tanzania (Teri and Mlasani, 1994) and Cameroon (Abang et al., unpublished). Alternaria blight is not considered to be a major disease of amaranth in sub-Saharan Africa. It is considered that Alternaria blight may impact yields in Tanzania but this is not supported by findings from recent surveys (Abang et al., unpublished). In South Africa, it was observed that isolates of the *A. tenuissima* group can infect and colonize *A. hybridus* leaves in a manner consistent with other endophytic fungi, suggesting that these fungi can act as latent leaf pathogens when the host is altered by wounding.

*Fusarium wilt (Fusarium oxysporum)*

In South Africa, isolates of this pathogen have been associated with stem decay (Blodgett et al., 1998) and root rot (Blodgett et al., 2004) of *Amaranthus hybridus* L., a nutritious, rapidly growing vegetable produced on increasing acreage in semi-arid regions of the country. The fungus also was shown to be the predominant fungal species vectored by the pigweed weevil *Hypolixus haerens*, the main insect pest of *A. hybridus* in South Africa. An integrated pest management program involving cultural practices, selection for disease resistance, and biological or chemical control of pigweed weevils should go a long way toward reducing losses associated with *F. oxysporum* in amaranth plantings (Blodgett et al., 2004).

*Choanephora blight (Choanephora cucurbitarium)*

This is a fungal infection predisposed by injuries. The disease is spread by air currents and infected seeds. Warm, moist conditions favor disease development. Wet rot of stems and leaves may cause heavy defoliation during the rainy season.

**Management:** Use resistant varieties where available. Plant certified disease-free seeds. Avoid dense planting to allow sufficient aeration. Practice good field sanitation.

*Virus diseases*

Amaranth was previously thought to be unaffected by viruses but a localized, severe virus disease attack recently was observed in amaranth fields in Arusha, Tanzania (Kenyon, Abang, Tsai, unpublished). Affected plants showed mosaic symptoms with proliferation of smaller leaves (shoestring symptoms). Samples from two of these plants have tested positive for begomovirus and preliminary results suggest that there are isolates of *Tomato leaf curl Arusha virus* (ToLCArV) and *Tomato leaf curl Uganda virus* (ToLCUV) present. This could be a first report for Tanzania since until now only *Ageratum enation virus-Lucknow* (AEV-[IN:Luc]; *Begomovirus*) has been associated with yellow vein net disease in grain amaranths in India. Management of virus diseases is the same as for African eggplant.

*Bacterial diseases*

No serious bacterial diseases have been observed or reported.

***Pests***

Aphids, leaf-webbers, stem weevils, and spider mites are the serious insect and mite pests that limit the productivity of amaranth.

*Aphids, Aphis spp. (Homoptera: Aphididae)*

The aphids suck the plant sap, leading to curled and wrinkled leaves, stunted plant growth and mortality of the plants due to severe infestations during the early stages. The morphology and management is similar to African nightshade.

*Leaf-webbers, Hymenia recurvalis Fab. and Psara basalis Walker (Lepidoptera: Pyralidae)*

The larvae web the leaves and feed concealed on the chlorophyll content. Complete skeletonization occurs due to severe infestations (Figure 70) and the leaves dry. The larvae of *P. basalis* bore in to the peduncle and stem, in addition to the usual defoliation (Kumar et al., 2008).

The larva of *P. basalis* is greenish and adults with head and thorax ochreous suffused with reddish or brownish red abdomen (Kumar et al., 2008) (Figure 71).

**Figure 70: Complete skeletonization due to severe infestation by leaf webbers**

**Figure 71: The adult moth of *H. recurvalis* has white wavy lines on the dark brown wings (left) and the translucent greenish larva of *H. recurvalis* has longitudinal white lines on its dorsal surface (right).**

Management practices include (i) clean cultivation – removal of weeds such as horse purslane (*Trianthema portulacastrum*), which serve as alternate hosts; (ii) cultivate amaranth away from crops such as corn, sugar beet, soybean, eggplant, spinach, sweet potato, etc., which serve as alternate hosts; (iii) protect parasitoids belonging to Braconidae (*Apanteles* sp.), Eulophidae (*Elasmus* sp.), and Ichneumonidae (*Trathala* sp.), as they are known to occur on leaf-webbers; and (iv) use of entomopathogenic fungi such as *Beauveria bassiana* offers more than 90% control of leaf-webbers (James et al., 2007).

*Stem weevil, Hypolixus haerens (Coleoptera: Curculionidae)*

Both the adults and grubs cause significant damages (Louw et al., 1995). Adults feed on the leaf lamina causing windows. They also feed on the growing tips and soft stems. The grubs bore into the stem, creating tunnels towards the roots and cause gall-like swellings at root collars, at which the plants are broken by strong winds. However, the grubs do not feed on the roots. In addition, the grubs also act as vectors for fungal pathogens such as *Fusarium subglutinans* and *F. oxysporum* in amaranth (Blodgett et al., 2004). The adult weevil is a dark grey insect with prominent snout.

Management practices include (i) removal and destruction of infested plants to reduce the population build-up; and (ii) conserve parasitoids such as *Entedon* sp. (Eulophidae) (Louw et al., 1995).

*Spider mite, Tetranychus sp. (Acarina: Tetranychidae)*

Spider mite feeding leads to the formation of white or yellow speckles on the leaves of amaranth. In severe infestations, mites also produce webbing on the leaf surfaces; eventually the leaves completely desiccate and drop off. The management practices are similar to African eggplant.

**Ethiopian mustard (*Brassica carinata* Braun)**

***Diseases***

The most important diseases in sub-Saharan Africa are black rot and *Turnip mosaic virus* (Varela et al., 2003).

*Black rot (Xanthomonas campestris pv. campestris)*

Black rot occurs on all cultivated crucifers and several wild species. Lesions typically begin at the leaf margin and progress inward forming V-shaped chlorotic lesions (Figure 72). With time the lesions begin to dry and become necrotic. Infection normally occurs through leaf pores, but may also start at any place on the leaf where insect or mechanical wounds allow for bacterial entry. The bacterium is a vascular invader and can move systemically in the plant. Invaded vascular tissue turns black in color; it can be seen as dark veins in lesions or by observing the vascular bundles in cross sections of the leaf midrib, petiole, or main stem of infected plants. Petioles and veins of diseased leaves are dotted black and affected stems when cut in transversely, show a characteristic black ring.

**Figure 72: Chlorotic V-shaped lesions at the leaf margin**

**Management:** Rotate with non-cruciferous crops for at least two years to allow time for debris from the previous crucifer crop to decompose. Use certified pathogen-free seed. Avoid working in the fields when the foliage is wet. Mulching of the field where feasible is highly recommended. Avoid overhead irrigation. Fields should be kept free of weeds, especially those of the crucifer family. It should be noted that fungicidal sprays do not control black rot disease. However, copper sprays might reduce the disease spread if traces of black rot are detected early in the field. Use resistant cultivars when available; black rot-resistant Ethiopian mustard cultivars have been developed.

*Turnip mosaic virus*

*Turnip mosaic virus* (TuMV) infects most cruciferous plants as well as beets, spinach, and tobacco, but is most damaging in Ethiopian mustard, Chinese cabbage, turnip, and radish. The most common symptom in these crops is a distinct mosaic of light and dark green colors on the leaves. Depending upon the virus strain and the crop species, necrotic streaks, flecks, or ringspots may also occur (Figure 73). Infected plants are stunted, with leaves coarsely mottled and distorted. The virus is transmitted by several species of aphids. The presence of virus source plants (infected crops or weeds), and conditions that favor migrating aphid populations will lead to a high incidence of TuMV infection.

**Management:** Locate seedbeds away from weedy fields. Avoid planting overlapping crops of species susceptible to TuMV. Aphicide sprays around and in seedbeds may reduce seedling infection and subsequent infection in the field. However, insecticidal sprays generally are not effective in reducing virus spread in crop fields (Abang et al., unpublished).

**Figure 73: Necrotic fleck and ringspot symptoms**

***Pests***

Ethiopian mustard is damaged by three important insects: diamondback moth, aphids, and Bagrada bug.

*Diamondback moth (DBM), Plutella xylostella L. (Lepidoptera: Plutellidae)*

The DBM larvae feed between the leaf tissues on the lower leaf surfaces, which leads to the appearance of windows or holes in later stages (Figure 74). Damage is confined to inter-veinal areas. Seedlings appear stunted because the growing tips are eaten.

**Figure 74: Holes caused by diamondback moth**

The adult moth lays eggs on leaves either singly or in groups of two to three. The larva is pale yellowish green to green in color. The matured larva is spindle-shaped, broader at the middle and tapering towards both the ends (Figure 75).

**Figure 75: Diamondback moth larvae**

The larval period varies between 10-30 days. Pupation occurs in silken cocoons on leaf surfaces, and the pupal period is about 5-15 days. The forewing margins of the adults have a series of yellow wavy markings, which come together to form diamonds when the wings are folded while the moth is at rest, hence the name “diamondback” moth. The adult longevity is about two weeks.

Management practices include (i) covering crucifer seedlings with a fine nylon mesh net to prevent DBM adults laying eggs on their leaves, which will postpone DBM infestation and reduce the need for control measures early in the season and help conserve natural enemies; (ii) using pheromone traps to monitor the adult males; (iii) releasing larval parasitoids *Cotesia plutellae* in lowlands and *Diadegma semiclausum* as well as the pupal parasitoid, *Diadromus collaris* in highlands; (iv) avoiding use of broad-spectrum chemical insecticides to control DBM that will kill the parasitoids and lead to the resurgence of DBM; (v) using biopesticides such as *Bacillus thuringiensis* or neem, both of which will complement the performances of the parasitoids (AVRDC, 2001); and (vi) intercropping with trap crops such as Indian mustard and repellent crops such as tomato. The tomato crop has to be planted 30 days before planting the vegetable brassicas. This method is highly effective when combined with a sprinkler irrigation system, which disrupts DBM flight activity and oviposition (Varela et al., 2003).

*Aphids, Brevicoryne brassicae L. and Lipaphis erysimi Kaltenbach (Homoptera: Aphididae)*

The aphids suck the plant sap, which causes general weakening of the plant. Leaves become curled, wrinkled, or cup-shaped. Black sooty mold grows on honeydew secretions from the aphids. With severe infestations, the leaves wilt and the entire plant dies. In addition, aphids transmit turnip mosaic virus disease.

Aphids are small, soft-bodied, and pear-shaped (Figure 76). They vary from yellow to green to black. Some have transparent wings and prominent eyes. They possess small tubes (tubercles) arising from either side of the back of their abdomen (tail region).

Management practices include (i) conserving natural enemies; (ii) removing cruciferous weeds; (iii) destroying and removing crop residues immediately after harvest; and (iv) avoiding the use of broad-spectrum insecticides early in the cropping season that will reduce the natural enemies, leading to a rapid increase in aphid populations.

**Figure 76: Aphids**

*Bagrada bug, Bagrada hilaris Burmeister (Hemiptera: Pentatomidae)*

The nymphs and adults suck the sap from the tender leaves, especially at the seedling stage, leading to the death of the plants.

The adult is a small black shield bug with black, white, and yellow spots with an orange cross on the back. The adults are winged. Nymphs are red with dark spots and a band around the abdomen.

Management practices include (i) removing cruciferous weeds to prevent a population build-up of the insect; and (ii) hand-picking and destroying the bugs.

**Jute mallow (*Corchorus olitorious* L.)**

***Diseases***

Only a few diseases affect jute mallow.

*Damping-off*

Damping-off caused by *Rhizoctonia*, *Pythium* or *Phytophthora* spp. occurs in seedbeds. These pathogens are managed through the use of raised beds, well-drained soils, and proper watering.

*Stem rot (Sclerotium rolfsii)*

Stem rot is a common disease during the dry season, causing plants to wilt. It is managed by deep plowing, using raised beds, rotating crops, and allowing ample time for breakdown of green manure before planting.

***Pests***

The most damaging pests of jute mallow are foliar feeding caterpillar and flea beetle, spider mite, and nematode (Palada and Chang, 2003).

*Leaf defoliator, Acraea eponina Cramer (Lepidoptera: Nymphalidae)*

*A. eponina* is the major limiting factor in jute mallow production (Matanmi and Hassan, 1987; Opabode and Adebooye, 2005). This is a polyphagous pest; it feeds on plants in families of *Ehretiaceae*, *Malvaceae*, *Solanaceae*, and *Sterculiaceae* (Silva-Brandao et al., 2008). The larva causes defoliation of the leaves.

The larva has four instars. The developmental period is about four weeks at room temperature (Matanmi and Hassan, 1987). The adult is an orange-colored butterfly. The wings have dark brown bands in the apex and outer margins with orange spots.

Management practices include (i) removing alternate host plants, which prevents population build-up; and (ii) conserving natural enemies such as parasitoids (*Carcelia normula* and *Charops* sp.) and predatory bugs (*Afrius figuratus* and *Rhynocoris bicolor*) (Matanmi and Hassan, 1987).

*Mallow flea beetle, Podagrica decolorata Duvivier (Coleoptera: Chrysomelidae)*

The adults of *P. decolorata* feed on the leaves of jute mallow, causing shot-holes. The damage is serious in young plants.

The larva is cylindrical and elongate. It has four instars and it is yellowish white, yellow, purple and pinkish brown in color for first, second, third and fourth instars, respectively. The larva has short hairs on the body (Atachi and Montcho, 2007). The adult is minute in size (3-4 mm long) and yellowish brown in color.

Management practices include (i) crop rotation; (ii) monitoring and early detection, especially during seedling stage; (iii) clean cultivation to reduce breeding sites and shelters; and (iv) covering the beds with fine-mesh nylon netting.

*Root-knot nematode (RKN), Meloidogyne spp. (Tylenchida: Heteroderidae)*

The infection due to RKN induces intense chlorosis, stunted growth, and significant reductions in leaf size and total fresh leaf weight. The infected roots are often predisposed to infection by other pathogens (Babatola, 1983).

Management practices include (i) crop rotation; (ii) addition of sufficient quantities of manure and other organic matter (ECHO, 2006); (iii) using sunhemp (*Crotalaria juncea*) as a trap crop (Haque et al., 2008); and (iv) applying neem leaf and cake extracts as protective treatments in soil infested with *Meloidogyne* sp. before sowing jute mallow (Agbakli et al., 1992).

**Okra (*Abelmoschus esculentus* L.)**

***Diseases***

*Damping-off (Pythium spp., Rhizoctonia solani (Kühn), Fusarium spp., etc.)*

Several species of the soil fungus *Pythium* cause mostly pre-emergence damping-off, while *Rhizoctonia solani* is more likely to be associated with post-emergence damping-off. There are many other seed- or soil-borne pathogens that can cause damping-off, including *Fusarium* and *Thielaviopsis* spp.

Pre-emergence damping-off causes rotting of seeds before germination and emergence or death of seedlings before they reach the soil surface, while post-emergence damping-off

occurs after seedlings have emerged from the soil but are still small and tender. Some seedlings do not die at once, but their roots are damaged and the stem girdled at the soil level. Such plants remain stunted. Damping-off is aggravated by excessive wetness of the soil, low soil temperatures, inferior quality seeds and failure to treat seeds with appropriate fungicides (Valera and Seif, 2004). The disease is a common cause of poor stands in seedbeds and fields.

Good agricultural practices for management of damping off include: (i) avoiding fields with a history of the disease and practicing crop rotation; (ii) avoiding fields previously planted to cotton or related crops; (iii) deep plowing of fields; (iv) use of certified, disease free seeds; (v) seed treatment with suitable, locally registered, and EU-permitted fungicides; (vi) avoiding over-irrigation and excessive fertilization with nitrogen (Valera and Seif, 2004).

*Black mold (Cercospora abelmoschi Ellis and Everhart)*

This disease is common in humid coastal areas and causes considerable damage in okra fields in Tanzania and Kenya. The fungus grows as a sooty to dark olivaceous mold on the underside of leaves (Figure 77), leading to leaf spots of various shapes. In severe epidemics under very humid conditions black mold also appears on the top surface. Seriously affected foliage rolls, wilts, and falls to the ground. The fungus survives from season to season in crop debris, and is spread by air currents and splashing water.

**Figure 77: Sooty mold on underside of okra leaves (left) and a wilted okra leaf (right)**

For GAP-compliant management of the disease, it is recommended that growers (i) avoid overlapping okra in the same field; (ii) rotate okra with maize, small grains or pulses; (iii) remove crop debris after harvest; (iv) deeply plow the field during land preparation; (v) avoid overhead irrigation; or (vi) spray with registered fungicides if black mold is severe. However, the severity should be determined by scouting the crop, and instructions on the fungicide label (for dosage, frequency of application, pre-harvest intervals and safety precautions) should be followed strictly.

*Powdery mildew [Leveillula taurica (Lev) Arnaud, Oidiopsis taurica Tepper]*

The disease is common in the semi-arid and highland areas, especially during the dry season. It attacks leaves, stems, flower buds, and pods. Yields of okra are reduced due to premature foliage loss. Increased humidity can increase the severity of the disease, and infection is enhanced during periods of heavy dew. The disease symptoms appear as subtle, small, round, whitish spots on leaves and sometimes stems. The spots enlarge and coalesce rapidly and a white mass resembling talcum powder becomes evident on the upper surface of older leaves or other plant parts. A large part of the talc-like powder on the leaf surface is composed of

spores. These spores are easily blown by winds to nearby susceptible plants. Heavily infected leaves turn yellow, then become dry and brown. Extensive premature defoliation of the older leaves can ensue if the disease is not controlled.

Healthy, vigorous leaves and stems are less prone to infection. Plants under nutritional stress in most cases will develop powdery mildew much sooner than plants of the same age grown under a good nutritional program. The plant should be well manured and fertilizers should be applied on the basis of standard recommendations. Growers should also (i) remove and destroy crop debris after harvest; (ii) keep okra fields free of weeds; (iii) avoid growing okra and related crops (e.g. cotton) in succession; (iv) irrigate regularly to avoid drought stress; or (v) spray fungicides under severe epidemic conditions. However, the severity should be determined by scouting the crop, and instructions on the fungicide label (for dosage, frequency of application, pre-harvest intervals and safety precautions) should be followed strictly.

*Fusarium wilt [Fusarium oxysporum f. sp. vasinfectum (Atk.) Synder Hensen]*

This disease persists in the soil for a very long time by producing special spores and can survive on plant debris and weed hosts such as *Amaranthus*, *Digitaria*, and *Malva*. Initially the plants show temporary wilting symptoms, which become permanent and progressive, affecting more leaves. The leaves of the affected plants show yellowing, loose turgidity and drooping symptoms, and are later shed. Eventually, the plant dies. In older plants, leaves wilt suddenly and vascular bundles in the collar region become yellow or brown. The fungus invades the root system and colonizes the vascular system. In doing so, water movement is blocked and toxins from the fungus alter normal cell function. Cutting the base of the stem reveals a dark woody portion. The pathogen is both seed- and soil-borne, and may be introduced inadvertently into fields though infected seeds or farm equipment. Water stress worsens the disease.

**Management practices:** (i) continuous cultivation of okra on the same piece of land should be avoided; (ii) avoid fields with a history of Fusarium wilt; (iii) in fields severely affected by the wilt pathogen, practicing long crop rotations is useful to reduce the pathogen population; (iv) use certified, disease-free seed; (v) raise soil pH by applying lime or farmyard manure where soil is acidic (do not use chicken manure, which is acidic); (vi) treat seeds with fungicide but follow label instructions when using the product; and (vii) avoid excessive fertilization, regularly irrigate the crop, keep fields weed-free, and control root-knot nematodes. Spraying with fungicides will not control this disease.

*Root-knot nematodes (RKN) (Meloidogyne spp.)*

RKN are soil inhabitants that attack a wide range of crops, particularly vegetables, and are spread with movement of infested soil and water, e.g. through irrigation water or farm implements. Affected plants are stunted and yellow and have a tendency to wilt or even die in hot weather. Affected plants typically appear in patches. The roots of affected plants have small lumps known as galls or root knots.

**Management:** Because root-knot nematodes are a major problem in okra growing areas, the following crops should not be included in a rotation with okra: tomatoes, paw paw, bananas, capsicums, potatoes, squash and sweet potato (Varela et al., 2003).

*Viruses*

Virus diseases present a major constraint to okra production in sub-Saharan Africa. In Cameroon, begomoviruses are suspected to be responsible for diseases in many crop species (Figure 78). These viruses are associated with characteristic begomovirus symptoms (leaf

curling and distortion, green or yellow foliar mosaic, stunting, and reduced yields). In Africa, two begomovirus species have been identified in okra: *Cotton leaf curl Gezira virus* in Egypt and Sudan, and *Okra yellow crinkle virus* in Mali. Both viruses were recently identified in Cameroon (Leke et al., 2007) and Tanzania (Ndunguru et al., unpublished).

**Figure 78: Okra with begomovirus symptoms**

*Okra mosaic virus* (OkMV) is a tymovirus which was first found in *Hibiscus esculentus* (okra) in Côte d'Ivoire (Fauquet and Thouvenel, 1987). OkMV is transmitted in a non-persistent manner by the coleoptera *Podagrica decolorata* (Brunt et al., 1990). The virus is also sap-transmissible.

Typical symptoms of OkMV on okra include vein-chlorosis, vein-banding, mosaic and stunting. Yields of affected crops are greatly reduced. Natural hosts of OkMV include jute mallow (*Corchorus olitorius*), roselle (*Hibiscus sabdariffa*), hibiscus (*H. rosa-sinensis*) and west African okra (*Abelmoschus caillei*). The virus was initially reported in Côte d'Ivoire and Nigeria only. It is likely to be widespread in many west African countries.

**Management:** Good growth of okra plants, low vector and virus infestation, and higher yields without pesticide use can be obtained by the netting method. In absence of netting materials, okra fields need to be protected up to at least 3 weeks from the attack of insect vectors and viruses for satisfactory yields. Besides using the recommended methods such as planting disease-free seedlings and uprooting the diseased plants, fields and nurseries should be protected from insect vectors as described for other crops. OkMV is very dificult to control with insecticides or by eliminating the virus hosts. There is limited information available on host resistance to OkMV. New okra crops should not be planted close to infected crops.

***Pests***

Okra is damaged by aphids, leaf beetles, flower beetles, cotton stainers, spider mites, African bollworm, and spotted and spiny bollworms.

*Aphid, Aphis gossypii Glover (Homoptera: Aphididae)*

This is called a cotton aphid or melon aphid because of their preferential feeding on cotton and melons. This is a serious pest on okra in several countries, including Kenya and Sudan.

Both the adults and nymphs suck the sap from tender leaves, growing shoots, and buds. The leaves become curled and covered with honeydew, which favors the growth of saprophytic fungi and causes sooty mold on leaves, which reduces the photosynthetic efficiency of the plants. In severe conditions, the plant growth is stunted.

The aphids are soft-bodied, pear-shaped insects with a pair of cornicles from the abdomen. They live in groups on the lower leaf surfaces (Figure 79).

**Figure 79: Aphids feeding on okra leaf**

Management practices include (i) not growing okra near an aphid-infested field or cotton field; (ii) monitoring and early detection; (iii) conserving natural enemies by not spraying broad-spectrum pesticides; (iv) avoiding excessive application of nitrogenous fertilizers (Varela and Seif, 2004); and (v) applying botanical pesticides such as neem.

*Leaf beetles, Podagrica spp. (Coleoptera: Chrysomelidae)*

*P. decolorata*, *P. sjostedti* Jacoby and *P. uniformis* Jacoby are the major flea beetles causing damages on okra in Ghana, Ivory Coast, and Nigeria. The adults feed on the leaves and cause shot-holes. They also feed on the cotyledons and stems in seedlings and young plants. The larvae feed on the roots without significant damage (Varela and Seif, 2004). In addition, *P. decolorata* transmits the *Okra mosaic virus* (Givord and Den Boer, 2008).

The adults may be black, brown, blue-green or yellow, depending on the species. Most of the management practices are similar to jute mallow.

*Flower beetles, Mylabris sp. (Coleoptera: Meloidae)*

The adult stage is the destructive stage. The adult is highly polyphagous and it feeds on the flowers of several plants in the families *Convolvulaceae*, *Cucurbitaceae*, *Leguminosae*, *Malvaceae*, etc. As they feed on the reproductive parts (Figure 80), these beetles cause significant yield losses. In general, they are minor pests, although occasionally infestations can be severe.

The flower beetles are also called “blister beetles,” because they secrete a compound containing cantharidin when disturbed. Cantharidin, a terpenoid, produces blisters on human skin upon contact. Flower beetles are brightly colored insects. The adult of *Mylabris* spp. bears red or reddish orange and black alternating bands on the forewing (elytra). The grubs feed on soil-dwelling insects, including pests, and do not cause any crop damage. The grubs have several instars, with two or more different forms of larva. The mobile first instar grub is known as “triungulin” because it has three-clawed legs. During subsequent instars, it becomes less active and then pupates.

As flower beetle populations are generally lower, they can be collected manually, wearing gloves or using insect nets, and destroyed.

**Figure 80: Flower beetle**

*Cotton stainers, Dysdercus spp. (Hemiptera: Pyrrhocoridae)*

Several species of cotton stainers feed on okra and cotton overwhelmingly. In addition, they also feed on silk cotton, roselle, etc. *D. cardinalis* Gerstaecker is the most common species damaging okra. Both nymphs and adults suck the sap from developing pods (Figure 81), drastically reducing yield.

**Figure 81: Cotton stainer**

The bugs are slender and elongated. The males are smaller than the females. The body color varies from grayish orange to yellowish red or red, with a black band on the wings. The abdomen has white bands (Varela and Seif, 2004).

Management practices include (i) not growing okra near cotton, roselle or silk cotton; (ii) collecting and destroying the bugs manually; (iii) proper tillage to expose the eggs; and (iv) prompt removal and destruction of all plants after the final harvest (Varela and Seif, 2004).

*African bollworm, Helicoverpa armigera Hubner (Lepidoptera: Noctuidae)*

The African bollworm is polyphagous and has been recorded as a damaging pest on 180 cultivated and wild plant species in at least 45 families (Venette et al., 2003).

The larvae prefer to feed on the floral buds, flowers, and young pods (Figure 82). The larvae bore holes in these parts and feed by thrusting their head inside the holes. The bore holes are circular and often surrounded by fecal pellets. Later, the larva feeds on most of the inner contents of the pod, eventually hollowing-out the pod. Severely damaged pods rot and fall down; partially damaged pods are deformed.

The adult African bollworm is a stout-bodied moth with a wingspan of about 35-40 mm (Figure 83). The males are usually pale yellow with olive green or grey color, whereas the females are reddish-brown in color. The larvae vary in color, ranging from pale green to brown or even black with lateral stripes on the body.

**Figure 82: African bollworm larva**

**Figure 83: Adult African bollworm moth**

Management practices include (i) avoiding growing tomato in the vicinity of other alternate host plants; (ii) strictly following crop rotation; (iii) using *H. armigera* sex pheromone traps to monitor, mass-trap or disrupt the mating of the male moths; (iv) planting African marigold

as a trap crop; (v) releasing egg-parasitoids (e.g., *Trichogramma pretiosum*) and larval parasitoids (e.g., *Campoletis chlorideae*) in okra fields at regular intervals; and (vi) using commercially available biopesticides such as *Bacillus thuringiensis* (*B.t.*), nucleopolyhedrovirus (HaNPV), and neem.

*Spotted bollworm, Earias vittella Fab. and spiny bollworm, E. insulana Boisduval (Lepidoptera: Noctuidae)*

*E. vittella* and *E. insulana* feed mostly on malvaceous plants and are the most damaging pests on okra and cotton. They are reported in several African countries.

The larvae feed on the growing shoot tips and cause wilting and drying of the terminal shoots in young plants. During the reproductive stage of the crop, the larvae feed on the flower buds and pods. Mostly, the larvae feed on of the inner content of the pods, and fill the pods with insect fecal pellets.

Adults are small moths with a wingspan of about 20 mm. The abdomen and hind wings are silvery or creamy white in color. The forewing of *E. insulana* is completely green in color, whereas *E. vittella* has a white forewing with wedge-shaped green band running from the base to the outer margins. The larvae of both the species are grayish brown (Figure 84). In addition, *E. insulana* larvae have black marks and orange spots on the thorax with small spines on the body.

**Figure 84: Spotted bollworm larva**

The management practices are almost similar to American bollworm.

**Pumpkin (*Cucurbita* spp.)**

***Diseases***

*Powdery mildew (Erysiphe cichoracearum and Sphaerotheca fuligena)*

Pumpkin is particularly susceptible to powdery mildew (Figure 85). Symptoms appear first as pale yellow spots on leaves and stems. Soon thereafter, sporulation becomes evident as white

powdery masses of conidia are produced over the lesion surface. Lesions frequently are numerous and coalesce to cover the entire leaf surface. Leaves become chlorotic, then turn brown and dry prematurely. The pathogens are obligate parasites and can persist on wild cucurbits or crop plants throughout the year in tropical and subtropical areas. Disease development can occur over a wide range of temperatures as long as there is sufficient moisture for spore germination and infection. These conditions can be provided by high relative humidity or dew formation in the absence of rainfall.

**Management:** Use resistant cultivars when available. Fungicidal sprays offer good protection for susceptible cultivars.

**Figure 85: Powdery mildew on pumpkin leaf**

*Downy mildew (Pseudoperonospora cubensis)*

The disease is most severe on cucumber and cantaloupe, but it attacks all cucurbit crops. Symptoms occur mainly on the leaves, where they begin as yellow angular spots becoming tan to brown with age. During periods of high moisture, sporulation may be evident to the naked eye on the lower surface of leaf lesions, where the sporangiophores protrude through stomata and produce pigmented sporangia abundantly. The pathogen is an obligate parasite that may exist on crop plants, volunteer crop plants, or wild cucurbits year-round in tropical and subtropical regions. Sporangia carried by air currents or rain splash are the main means of disease dissemination. Disease development can occur over a wide temperature range under conditions of high humidity resulting from dew, fog, or rainfall.

**Management:** Use resistant cultivars when available. Fungicidal sprays are important in the absence of resistant cultivars when the crop is grown under conditions conducive for disease development.

*Alternaria leaf spot (Alternaria cucumerina)*

Each pathogen is highly specialized attacking only a single crop species. Plants may be affected at any stage of growth. Young seedlings are killed or severely stunted. Older plants begin to wilt at midday for a few days, then permanently wilt and die. Vascular bundles are discolored becoming yellow or brown. The pathogens can persist in the soil for many years.

The disease can move from field to field in soil on farm machinery, infected crop debris, and irrigation water. High soil temperatures favor disease development.

**Management:** Use resistant varieties when available. Avoid known infested fields for production of a susceptible crop. Wash equipment when moving from one field to another. Flooding fields for rice production reduces pathogen survival in the soil.

*Viruses*

These are among the most important yield limiting factors in pumpkin production. Aphid-transmitted viruses attacking pumpkins are *Cucumber mosaic virus* (CMV), *Papaya ringspot virus* (PRSV-W2), *Watermelon mosaic virus* (WMV-2), and *Zucchini yellow mosaic virus* (ZYMV). The whitefly transmitted geminivirus, *Squash leaf curl virus* (SLCV), the seed-transmitted comovirus, and *Squash mosaic virus* (SqMV) also attack pumpkin.

**Management:** Early planted fields tend to have less damage than those that are planted later. Control weeds within and around fields. Attempts to use insecticides to control insects and thus reduce disease severity may be futile, because insects may transmit the virus before insecticides are effective.

*Root-knot nematodes (RKN) (Meloidogyne incognita and Meloidogyne spp.)*

All cucurbit crops are susceptible to RKN. Above-ground symptoms include reduced growth, pale green or yellow foliage, and plants that tend to wilt with only a minimum of water stress. Underground symptoms are most characteristic for the disease with root galls two to three times the diameter of healthy roots, which give the root system a knobby appearance. Decay of infected roots is common in advanced stages due to invasion by secondary organisms. The nematode can survive in a dormant egg stage for a few months and on susceptible plant hosts indefinitely. The disease is most severe in light sandy soils and at relatively warm soil temperatures. If populations of the nematode are high in the soil from a previous crop, losses can be very great. The disease occurs commonly in field or glasshouse grown crops.

**Management:** Resistant cultivars should be used when available, but resistance is usually specific for a particular *Meloidogyne* sp. and may not hold up in all cases. Soil fumigation or pasteurization is the most effective means of root-knot control. Crop rotation, fallow plowing, and deep plowing can reduce nematode populations in the soil. Crop rotation with a flooded crop such as rice can greatly reduce population levels.

***Pests***

*Fruit flies, Bactrocera spp. (Diptera: Tephritidae)*

*B. cucurbitae* Coquillett and *B. invadens* Drew, Tsuruta & White are the major fruit fly species damaging pumpkin in Africa. The female fly thrusts the white, elongate eggs inside the tender fruits (Figure 86).

The oviposition points can easily be identified with oozing liquids and decaying tissues (Figure 87). The maggots (Figure 88) feed on the pulp and immature seeds inside the fruits, causing premature dropping of fruits. The adult is yellowish brown or reddish brown, with yellow markings on the thorax (Figure 89).

Management practices include (i) prompt collection and destruction of infested fruits; (ii) disposing of the crop residues immediately after harvest; (iii) using baited traps to attract and kill the adults; (iv) constant stirring of the soil in infested fields to kill the pupae; (v) using

protective covering such as wrapping of the fruits; and (vi) applying botanical pesticides such as neem to prevent oviposition.

**Figure 86: Fruit fly maggots**

**Figure 87: Fruit fly oviposition**

**Figure 88: Damage due to fruit fly maggots**

**Figure 89: Adult fruit fly**

**Vegetable cowpea (*Vigna unguiculata* [L.] Walp.)**

***Diseases***

Bacterial, fungal, and viral diseases, as well as nematodes and parasitic weeds are known to limit the yield of vegetable cowpea in sub-Saharan Africa. The major disease problems of cowpea result from infection with three seed-borne organisms: bacterial blight (*Xanthomonas campestris* pv. *vignicola*), brown blotch (*Colletotrichum truncatum*) and cowpea aphid-borne mosaic virus. These diseases can substantially reduce yield, and because the pathogens are seed-borne, the diseases can be widely distributed.

*Bacterial blight (Xanthomonas axonopodis pv. vignicola)*

This seed-borne disease appears as tan to brown angular leaf spots with yellow margins on leaves, pods, and stems. It may cause severe defoliation during periods of high humidity. Bacterial blight is transmitted from infected seedlings to adjacent plants by rain drops and causes chlorotic patches (orange with a yellow halo) and necrotic patches on the leaves. The pathogen also can cause cracking and cankers on the stem and peduncles. The disease is endemic to the semi-arid Sahelian zone.

**Management:** Use certified disease-free seeds. Avoid working in the fields when it is wet. Practice good field sanitation. Plant less susceptible varieties, if available, and follow cultural practices such as land and crop rotations. Registered bactericides should be used according to extension advice and label instructions.

*Brown blotch (Colletotrichum truncatum)*

The fungus causes pre-emergence and post-emergence damping-off when infected seeds are planted. The former rots the seed before emergence from the soil while post-emergence kills the seedlings after emergence. The disease also attacks the foliage, stems, and pods. Sunken, oval spots may be seen on stems; circular spots on leaves. Lesions are reddish-brown. Under prolonged wet weather heavy defoliation occurs. It’s transmitted through infected seeds and survives in crop debris.

**Management:** Use certified disease-free seeds. Use resistant varieties, where available. Practice good field sanitation.

*Rust (Uromyces vignae)*

Small, reddish-brown pustules (blisters) appear on both upper and lower leaf surfaces. Rust can develop rapidly, resulting in severe leaf damage and defoliation.

**Management:** If soybean rust is confirmed in an area or a field, consult your local extension agent or crop adviser immediately about fungicide spray application. Fungicides will likely reduce the potential yield loss, depending on plant developmental stage, timing and application method. Do not spray sulphur when it is hot, as it can burn the foliage and flowers.

*Cowpea mosaic diseases*

These viruses produce a mosaic pattern on cowpeas. They may be found singularly or in combination with others. They cause irregular light and dark green mosaic patterns in the leaves. Some viruses cause thickened, malformed leaves. The mosaic patterns are best observed on the younger foliage. Plants may be stunted and fail to produce normal pods. If the disease attacks plants at the early growth stage, no pods should be expected. Mosaic diseases include: *Cowpea mosaic comovirus* (CpMV), *Blackeye cowpea mosaic potyvirus* (BICMV), *Cowpea severe mosaic virus* (CPSMV), *Cowpea aphid-borne mosaic potyvirus* (CAMV), *Cowpea mottle carmovirus* (CPMoV), and *Cowpea golden mosaic bigeminivirus*. The most common virus disease on cowpeas is *Cowpea aphid-borne mosaic potyvirus*. It is transmitted by aphids, causes distortion and mottling of the leaves, and can stunt the plants.

**Management:** Plant resistant varieties, where available. Use healthy, certified pathogen-free seeds rather than saving seed from a crop that could be infected. Practice crop rotation with non-legumes (e.g. cereals). Remove alternative hosts of virus diseases (legumes).

*Charcoal rot or ashy stem blight disease (Macrophomina phaseolina)*

The most striking symptom is the sudden wilting and drying of the whole plant, with most of the leaves remaining green. The stem and branches are then covered with black bodies and give the charcoal or ashy appearance of dead plants. Withering can be observed from seedling to maturing stage and is the result of necrosis of roots, stems and mechanical plugging of xylem vessels by microsclerotia, but also by toxin production and enzymatic action.

**Management:** Rotation with unrelated crops (e.g. cereals) helps reduce the population of the fungus in the soil. Avoid moisture stress by increasing the moisture-holding capacity of the soil and, if available, using irrigation when needed. Rotate with crops that are not seriously affected by this organism. Practices that hasten decomposition of crop residue may help decrease the population of the fungus in the soil. The fungus can cause substantial damage to cowpea when soils became dry and hot.

*Stem rot (Phytophthora vignae)*

The most important disease of cowpea in South Africa is stem rot. Plants yellow-off and begin to die back in patches. When removed from the soil, a light brown area may be seen completely girdling the base of the stem. In moist conditions, the upper part of the plant may be attacked directly, causing a withering and collapse of the stem. The disease mostly occurs in wet and waterlogged conditions. Management: Control of *P. vignae* in cowpea is principally through the use of resistant varieties. Metalaxyl was found to be the most effective compound for control of stem rot (Fernando and Linderman, 1994). The pathogen is very long-lived and persistent in the soil. Maintain at least a four-year break between cowpea crops in the same field.

### *Pests*

The cowpea is severely damaged by flower thrips, aphids, and the legume pod borer in Africa.

*Bean flower thrips, Megalurothrips sjostedti (Trybom) (Thysanoptera: Thripidae)*

Thrips is one of the major pests of cowpea in tropical Africa and it is the first one appearing on the cowpea plant (Taylor, 1974). It attacks the reproductive organs, thereby causing yield losses up to 100% (Singh and Allen, 1980a, b). Thrips feed on the floral buds and flowers, and are more prevalent during cold and rainy periods.

Management practices include (i) increasing plant spacing up to 1.2 m to decrease thrips damage (Asiwe et al., 2005); (ii) using arbuscular mycorrhiza fungi, rhizobia, and *Metarhizium anisopliae* can significantly reduce thrips infestations (Ngakou et al., 2008); (iii) using tolerant cultivars such as IT91K-180 (Alabi et al., 2004); (iv) spraying neem seed kernel extract (Tanzubil et al., 2008); and (v) conserving larval parasitoids such as *Ceranisus menes* and *C. femoratus* (Tamò et al., 2002).

*Cowpea aphid, Aphis craccivora Koch. (Homoptera: Aphididae)*

This aphid is highly polyphagous. A large number of aphids colonize in the growing shoots, young leaves, and pods (Figure 90) and suck the sap, leading to general weakening and stunted growth of the plants. The honeydew deposits favor the growth of sooty mold and reduce the photosynthetic efficiency of the plants. Management is similar to other aphids.

**Figure 90: Aphids colonizing vegetable cowpea**

*Legume pod borer, Maruca vitrata F. (Lepidoptera: Pyralidae)*

The larvae feed on floral buds, flowers, and immature pods (Figure 91). The larval head is dark brown, and the body is whitish to pale brown in color with brown black spots (Figure 92). The larva has five instars. The adult has brownish black forewings with white patches and white hind wings with an irregular brown border in the apical margin.

**Figure 91: Legume pod borer larva**

**Figure 92: Spots on legume pod borer larva**

Management practices include (i) monitoring with sex pheromone traps (Downham et al., 2002); (ii) using biopesticides based on *B. thuringiensis* (Srinivasan, 2008); using nucleopolyhedrosis virus (Lee et al., 2007) and neem; and (iii) conserving parasitoids such as *Apanteles taragamae* and *Bassus asper* (Tamò et al., 2002).

## CONCLUSION

Although pesticide use in Africa makes up only 4% of the global pesticide market, there are serious hazards arising from the toxicity of the compounds used in Africa and shortcomings in handling practices, such as lack of protective equipment (PAN, 2007). In this paper, we have sought to dispel the myth that pests and diseases are not important in indigenous vegetables or that pesticide use in these vegetables is negligible. We also show how excessive reliance on pesticides can be avoided through the diversification of disease and pest control measures. A common misconception is that pesticide health and environmental impacts in Africa are mainly related to large-scale farms, while smallholder farming systems are generally viewed as low input, with minimal or zero use of pesticides. This ignores the fact that many cash crops (including indigenous vegetables) are grown predominantly by smallholders, who use the same pesticides singly or in mixtures for a range of crops. AVRDC-The World Vegetable Center and its national and international partners strive to enhance the productivity of indigenous vegetables in developing countries through the

development and dissemination of improved varieties and other GAP-compliant technologies. The Center's research focuses on IPM, IDM, balanced fertilization, and improved water and nutrient management for increased production efficiency and product safety. Multistakeholder involvement and farmer/consumer participation in technology development, adaptation, and delivery are seen as key requirements for the acceptance and adoption of these technologies by end users.

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# Food Preparation and Processing Methods on Nutrient Retention and Accessibility in Selected Indigenous Vegetables from East Africa

**Mel O. Oluoch[1,2,*], Florence O. Habwe[3], Joyce B. Ngegba[4], Kipkorir R. Koskei[5] and Ray-Yu Yang[6]**

*[1]AVRDC-The World Vegetable Center, P.O Box 10, Duluti, Arusha, Tanzania*
*[2]International Institute of Tropical Agriculture (IITA), P.M.B. 3112, Kano, Nigeria*
*[3]School of Public Health, Maseno University, P.O. Box 333-40105, Maseno, Kenya*
*[4]Department of Food Science & Technology, Sokoine University of Agriculture, P.O. Box 3006, Morogoro, Tanzania*
*[5]Department of Food Science, Egerton University, Njoro, Kenya*
*[6]Nutrition, AVRDC-The World Vegetable Center, Shanhua, Tainan, Taiwan*
**Corresponding author (m.oluoch@cgiar.org)*

**Abstract**

In Africa, indigenous vegetables are a common food source and rich source of micronutrients such as carotenoids, vitamin C, calcium and iron. However, food preparation and processing operations affect contents and bioavailability of micronutrients in vegetables. Several studies have been carried out to investigate the influence of local food preparation and processing methods on iron and carotenoid accessibility of vegetables including African indigenous vegetables (AIV) such as African nightshade (*Solanum scabrum*), amaranth (*Amaranthus blitum*), slenderleaf (*Crotalaria ochroleuca*), sweetpotato leaves (*Ipomea batata*) and cowpea leaves (*Vigna unguiculata*). Different experiments showed that cooking vegetable mixtures from either two of these AIV together increased iron accessibility when compared to cooking one vegetable. Fried recipes had significantly higher iron content compared to boiled ones and raw vegetables. Improved recipe formulation may increase AIV acceptability and consumption and thus increase iron intake. An additional study on cooking and drying effects on carotenoid and flavonoid retention in two nightshade species (*Solanum scabrum* and *Solanum villosum*), showed that oven drying retained carotenoids while drying in direct sun and under shade cause a significant decrease in the carotenoid contents in both nightshade species. Cooking (boiling in water for 10 min) did not affect the levels of lutein and β-carotene but caused total loss of violaxanthin and neoxanthin. Cooking also reduced flavonoid content while oven drying, drying in direct sun and under shade did not affect the flavonoid content of *Solanum scabrum* sp. In vitro simulated gastro intestinal digestion caused a loss of approximately 80% in the carotenoid contents of the two nightshade species, and also revealed that the accessibilities of iron, carotenoids and flavonoids are improved more in the cooked leafy vegetables than in the raw, oven dried and sun dried samples. Another study investigated feasible food preparation methods to increase carotenoid retention and iron bioavailability of leafy vegetable dishes traditionally prepared by Tanzanian households. Results showed that modified traditional preparation methods with appropriate ingredients improve the retention of lutein and β-carotene; and iron accessibility in sweetpotato leaves. Specific cooking, preparation and preservation practices of AIV that are compatible with local experience can be encouraged as an alternative or adjunct to other methods of increasing the availability of micronutrients in foods.

## INTRODUCTION

Micronutrients deficiency, also known as hidden hunger, is a public health problem that is affecting a huge proportion of human population especially in developing countries. Most physiological disorders, poor health, reduced productivity, reduced intellectual potential and increased mortality are associated with it (Maberly et al., 1994; Friis, 2005). Vitamin A and iron are among the two nutrient deficiencies of public interest as they affect over 2 billion people worldwide. It is estimated that 25% of preschool children and 18% of women are vitamin A deficient; whereas 37% of the world's total population is iron deficient (Borwankar et al., 2007). Data for developing countries show that about 40% of the population suffers from iron deficiency and 40% of children are growing up with insufficient vitamin A (UNICEF, 2004). In Tanzania, 65% of children under 5 years of age suffer from iron deficiency while 37% are estimated to have sub-clinical vitamin A deficiencies (UNICEF, 2004). The prevailing situation calls for urgent and effective measures to overcome micronutrient deficiency, which is precondition for ensuring rapid and appropriate development.

Strategies to combat micronutrient deficiencies include fortification, biofortification, supplementation and other food based approaches. Fortification involves addition of nutrients in foods and other consumable products. However, fortification has been associated with increased price of fortified foods and difficulties in enforcement of fortification regulations (FAO, 1997). Biofortification is the process of breeding crops that are richer in nutrients. It has the advantages of targeting rural areas, being cost-effective and it is sustainable. Supplementation provides nutrients other than those taken in the normal diets (SCN, 1993). However, the routine provision of single micronutrient supplementation has not been effective in combating the coexisting micronutrient deficiencies in developing countries (Gibson, 2004). Supplements and fortified foods are also often not widely available in rural areas. Among all the strategies, food based strategies seem to be a sustainable solution to micronutrients deficiencies especially in developing countries (WHO, 2001; FAO/WHO, 2003). The strategies involve intake of micronutrients rich foods such as fruits and vegetables and optimizing processing methods (Tontisirin et al., 2002).

African indigenous vegetables (AIV) such as nightshade (*Solanum scabrum* and *Solanum villosum*), amaranth (*Amaranthus blitum*), cowpea (*Vigna unguiculata*), jute mallow (*Corchorus olitorius*), and spiderplant (*Cleome gynandra*), play a highly significant role in the food security of underprivileged both in rural and urban settings in Africa. They act as valuable sources of micronutrients, fiber, and bioactive compounds such as iron, carotenoids and antioxidants in the diets of most communities. They are sometimes better nutritional sources than the modern vegetables (Sato et al., 2002; Rensburg et al., 2004; Yang and Keding, 2009). They also require less capital investments, less-labor intensive management and are better adapted to local conditions. A study in Tanzania showed that most of the indigenous vegetables were preferred by 50 to 90% of the people surveyed (Lyimo et al., 2003; Keding et al., 2008). Since the vegetables are affordable they provide a sustainable source of micronutrients to rural and urban families (Sato et al., 2002).

In spite of the proven potential of indigenous vegetables in alleviating micronutrient deficiency in sub-Saharan Africa, they are often neglected in research (Rensburg et al., 2004; Madisa and Tshamekang, 2006). A number of studies in Africa (Mwajumwa et al., 1991; Raja et al., 1997; Kinabo et al., 2004) have focused on nutritive value of the uncooked vegetables (Msuya et al., 2008). Therefore, information about nutrients in cooked vegetables is insufficient (Marcela and Rodriguez-Amaya, 2004). Studies on traditional vegetable processing methods in Tanzania found significant nutrient losses (Mosha et al., 1997; Lyimo et al., 2003; Mulokozi et al., 2004; Msuya et al., 2008). Other studies elsewhere reported changes in physical and chemical composition in vegetables due to cooking and other processing methods (Severi et al., 1998; Reddy and Love, 1999; Turkmen et al., 2005).

Indigenous vegetables play an important role in food security of most African populations in both rural and urban settings. Although the consumption and use of AIV are still rooted in the practices and knowledge systems of Africa's rural people, the current neglect and loss of processing knowledge may soon translate into disuse and eventual loss of these vital nutritional and economic resources. AIV are a valuable source of nutrition in rural areas and they contribute substantially to protein, mineral and vitamin intake. They are compatible in use with starchy staples and represent a cheap but quality nutrition to the poor sector of the population in both urban and rural areas where malnutrition is widespread (Maundu, 1997; Weinberger and Msuya, 2004). AIV can also play a significant role in addressing three major factors of low income, malnutrition and loss of biodiversity that greatly affect the quality of life of resource-poor households in Africa. AIV can be used as cash crops in peri-urban systems, source of new crops, source of vegetables for daily sustenance in home gardens; and as source of variation for diversification of production systems and diet. However, this has been hindered by lack of variety in recipe formulation in AIV.

## HIGH IRON RECIPES

AIV production can compensate for low vegetable supply during the off-season, potentially helping to alleviate nutrition deficiency during this period (Engle and Altoveros, 2000). While most AIV are nutritious if well cooked, surveys carried out showed that preparation and cooking procedures used in households could lead to a decrease of the nutritive value of cooked vegetables (Waudo et al., 2007; Ngegba, 2007). This therefore emphasizes the need to develop recipes so that people become informed on the best methods of food preparation, which can help minimize nutrient loss and at the same time increase acceptability and thus increase consumption.

Formulation of high iron recipes from AIV could enhance the acceptability and consumption of iron rich indigenous vegetables that can complement insufficient iron supply of current exotic vegetable consumption. It will also help eliminate economic implications of anemia in terms of reduced work capacity and food insecurity, which create the vicious cycle of malnutrition. Studies on recipe formulation in AIV encourage consumption, which could lead to the AIV being used more as a source of vegetables for daily sustenance of home gardens, and as a source of diet diversification and production systems; which could result in nutrient and food security. These vegetables are also seasonal and recipe formulation and development of vegetable products promises availability of these vegetables throughout the year, which will also help reduce wastage.

A study carried out in Kenya has shown a positive correlation between taste and appearance. Demographic factors such as age and sex, as well as whether the vegetables are cooked as a single vegetable or in combinations do not have any effect on vegetable acceptability. When raw, boiled and fried indigenous vegetables in different combinations were analysed for vitamin C, iron and copper content, it showed increased or reduced accessibility when nutrients are consumed simultaneously. For example a combination of nightshade and cowpea in a recipe increases carotenoids and vitamin C content of the cowpea dish, which is higher than the quantity in single vegetables of nightshade and cowpea. On the other hand a combination of nightshade and sunhemp reduces vitamin C content compared to single combinations and also the rest of the vegetable combinations (Habwe, 2008). When selected AIV were screened for iron content in raw, boiled and fried form, results showed that cooking in fried form significantly increases iron accessibilty of AIV (Habwe et al., 2009). A combination of amaranth and slenderleaf significantly increases iron content while a combination of nightshade and slenderleaf reduces iron content compared to the rest of the vegetable combinations (Habwe et al., 2009). Additionally, cooking in frying form significantly increases copper content of AIV when compared to boiled and raw vegetables. There is no effect on both iron and copper contents when the AIV are cooked as single

vegetables or as vegetable combinations (Habwe et al., 2009; Habwe, 2008). In general, to minimize nutrient loss such as vitamin C, copper and iron, frying is the best cooking method.

Dietary change programmes may be more suitable at the family and community levels where AIV are locally available. The change can be accelerated with the availability of nutrient composition data and recipes that show how well to prepare these vegetables so as to ensure minimum loss of nutrients. Availability of these recipes can encourage individuals to consume more nutrient rich AIV.

## TRADITIONAL AND MODIFIED PREPARATION METHODS

Most researchers have concentrated on the production aspects of AIV yet lack of recipe formulation and information may contribute to low consumption. These vegetables are also seasonal and recipe development can make available these vegetables throughout the year by helping reduce wastage and increase diet diversification. The increased availability may contribute to nutrient and food security. Food processing has advantages of preserving food and nutrients, tasteful and shelf-stable or better digestibility. It plays a role in increasing digestibility and improving food flavour or quality by destruction of oxidative enzymatic reactions and anti-nutrient components.

AIV constitute part of the traditional legume and cereal based diets and provide dietary carotenoids and iron. However, the legume and cereal based diets are characterized by a high level of nutrient inhibitors such as phytic acid, which reduces the bioavailability of minerals (Ruel, 2001). The contents and bioavailability of some key micronutrients in foods can be enhanced by right food combinations and appropriate food processing methods (Gibson, 2007; Tontisirin et al., 2002).

Indigenous vegetables were widely consumed in Tanzania before exotic species were introduced. The vegetables are more available and consumed in rural areas where exotic species are limited due to high cost and other factors (Lyimo et al., 1991). Households consume vegetables on the basis of taste, availability and affordability (Sato et al., 2002). Most indigenous vegetables are available during the rainy season. They are cultivated in farms, gathered from the wild or grown in home gardens (Keller et al., 2005). In semi-arid areas, where their availability is seasonal, they are dried traditionally and preserved for consumption during dry season (Mosha et al., 1995; Keller, 2004; Mulokozi et al., 2004).

Vegetables in Tanzania are prepared in different ways and with varying cooking methods. Different ingredients are added at varying proportions and therefore it is difficult to obtain standard recipes from the communities (Weinberger and Msuya, 2004). Hence, there is a gap in knowledge regarding carotenoids and iron bioavailability of vegetables under varying cooking methods and the enhancement of these micronutrients. A study has been carried out to investigate feasible food preparation methods to increase carotenoid retention and iron accessibility in leafy vegetable dishes traditionally prepared by rural households in Tanzania (Ngegba, 2007). The study was carried out to generate information that could help guide households in identifying and utilizing indigenous vegetable recipes that are of high nutritional quality, locally available, low cost, and could ultimately help in improving their food security and nutritional status.

The study of Ngegba (2007) and Ngegba et al. (2008) showed that the five most cooked vegetables in Kongwa, Singida and Arumeru districts in Tanzania are amaranth, jute mallow, sweet potato leaves, nightshade and African eggplant. Boiling, stir-frying and open-sun drying are some of the most used methods for cooking and preservation but the preferred method in each district is crop specific (Ngegba, 2007). Improved modified food preparation methods have shown to be better than traditional methods in terms of nutrient retention. Traditional preparation methods retain the carotenoids in a range of only 16-70%, whereas

modified methods retain carotenoids in a range of 60-116%. On the other hand, iron accessibility was also improved when vegetables are prepared by modified methods. Pro-long cooking and reheating of cooked indigenous vegetables are mostly responsible for significant reduction of carotenoid retention and iron accessibility in dishes prepared by traditional methods (Ngegba, 2007; Ngegba et al., 2008).

Amongst the modified preparation methods, the use of oil in combination with tomato and lemon helps to improve the lutein, β-carotene retention and iron accessibility in sweet potato leaf dishes. Additionally, vegetable recipes that include soybean as ingredient increase iron accessibility to a comparable level with dishes cooked with oil, probably due to the presence of oil in the soybean (Ngegba, 2007; Ngegba et al., 2008).

It is recommended that improved preparation methods such as boiling for a short time, avoiding coiling and draining vegetables in the sun, washing before cutting and retaining of boiled stocks or soup are highly recommended as best practices for preparation and processing of leafy vegetables. Oven-drying with 50°C is also recommended as a better way of preserving nutrients in vegetables than solar drying. However, availability of ovens is not practically feasible, especially in rural settings where there is no electricity and thus indirect sun-drying methods should be used such as solar cabinet dryers and blanching prior to drying (Ngegba, 2007; Ngegba et al., 2008).

## FOOD PREPARATION PROCESSES AND IN VITRO GASTRO-INTESTINAL DIGESTION

Food-derived flavonoids and carotenoids have been reported to play a significant role in health maintenance and prevention of disease (Milner, 1999; Yang et al., 2007, 2008). Some reports have documented the losses of nutrients from vegetables during drying (Yadav and Sehgal, 1997) and cooking (Kachik et al., 1992). Sun-drying in direct sunshine or under shade are the common practices used in most parts of Africa to preserve vegetables for dry season consumption (Lyimo et al., 1991). However, food preparation and preservation techniques may affect significantly the concentration and availability of minerals, vitamins and other essential compounds contained in food. Studies have been undertaken to determine the effects of food processing methods such as cooking, sun-drying and oven-drying on carotenoids and phenolic antioxidants of nightshades (Koskei, 2006). Additional studies on in vitro digestion have also been undertaken to determine the bioavailability and/or accessibility of iron, carotenoids and phenolic antioxidants of nightshade leafy vegetables (Koskei, 2006).

Results have shown that cooking, oven drying, drying in direct sunshine and drying under shade have significant effects on the concentrations of carotenoids and flavonoids of two nighshade species *Solanum scabrum* and *Solanum villosum*. Cooking has little effects on β-carotene and lutein contents but leads to total loss of violaxanthin and neoxanthin contents in both species. Oven drying has little effect on carotenoid content of leafy vegetables such as nighshade but drying in direct sunshine and under shade significantly reduce the levels of carotenoids in nightshade (Koskei, 2006).

Different species respond differently to processing methods and it has been shown that in nightshade, cooking, oven drying, drying in direct sunshine and drying under shade have little effects on the flavonoid content of *Solanum scabrum* but affect the flavonoid content of *Solanum villosum* species (Koskei, 2006). In vitro gastro-intestinal digestion also shows that dialysability of iron and bioaccessibility of carotenoids and flavonoids are improved more in the cooked leafy vegetables than oven dried and sun dried samples. However, the concentrations of iron, carotenoids and flavonoids were higher in *Solanum scabrum* than in *Solanum villosum* while the bioaccessibility of these substances occur more in *Solanum villosum* than in *Solanum scabrum* species (Koskei, 2006).

## CONCLUSION

The best practices for vegetable preparation methods that preserve micronutrients should involve: short cooking times, adding vegetables to boiling water rather than cold water before heating, covering of vegetables while cooking, boiling the vegetables in just enough amount of water, and boiling before frying rather than intensive frying. Additionally, modified preparation methods with enhancing ingredients provide better results in improving iron bioavailability in vegetables than traditional preparation methods. Drying in direct sunshine and drying under shade cause greater losses of flavonoids and carotenoids from the leafy vegetables although the effect varies by species.

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# Conclusions

## GUIDELINES TO DEVELOP AIVS GAPS

Specific issues that must be considered when developing technical guidelines for good agricultural practices of AIVs were discussed. These include breeding to develop practices focused on yield improvements, adaptability to biotic and abiotics stresses, desired maturity time and quality improvements (improving nutritional and nutraceutical properties and reducing antinutrient factors).

AIV production should begin with clean seed/planting materials, and be accompanied with appropriate agronomic packages that take into account health and environmental sustainability.

Soil fertility, land management aspects and safe use of irrigation water are aspects of resource management that should also be considered. Appropriate timing for planting and pest management to proper harvesting stages should be supported with proper record keeping. Time and methods of harvesting, appropriate post-harvesting handling of produce, transportation, processing and packaging are all important pillars of good agricultural practices.

While developing guidelines of GAPs on AIVs it is also important that consumers should be educated on the food nutritional value. Informative labeling for produce including appropriate recipes should be developed and made available. If possible these should be enforced as a policy.

## RESEARCH AND DEVELOPMENT FOR AFRICAN INDIGENOUS VEGETABLES

The group proposed that a multidisciplinary network approach to research and development should be applied for identification of priority species locally. The network could be based on vegetable groups that could be broadly classified as leafy and fruit & other vegetables crops. The networks should be regional with possibility for exchange of information among countries. The research priority areas identified by the group were crop husbandry, planting material and seed technology, and crop improvement (plant breeding).

The economic importance of the crops depends on their level of utilization and nutritional value; approaches to crop value addition including crop protection should be considered. With regard to crop husbandry nursery management, nutrient requirement and fertilizer management spacing and plant establishment and irrigation and water management are critical issues.

Aspects that should also be considered with regard to planting and propagation material include optimization of seed quality (seed germination, seed dormancy and seed storage), vegetative propagation materials (micro-propagation methods) as well as development of seed systems.

Crop improvement could take the form of germplasm collection and evaluation/characterization, participatory plant breeding resulting in development and release of new varieties. Issues of intellectual property rights should be given priority to enhance utilization without intimidation.

Crop protection would involve identification of pests and diseases, development of management strategies with emphasis on non chemical measures, safety of biological control agents and the environment in general, and maximum residue levels (MRL) to reduce crop yield loss.

Economic importance of the crop should be enhanced by improving utilization through promotion and awareness creation, capacity building (training in crop value addition; curricular development to include AIVs).

## STRATEGIES FOR POST-HARVEST HANDLING AND MARKETING OF AIVS

### Post-harvest issues

One of the critical post-harvest issues is packaging and handling that should be done with proper labeling for traceability purpose as well as providing information about nutritive value of the vegetables, thus allowing the consumer to make informed choices. The labels should include harvesting and expiry date, the quality and quantity. The packaging material should be net and durable for consumer appeal and product storability.

Proper storage environment (temperature humidity, pre-cooling) should be considered to reduce post-harvest losses. Safe and hygienic handling (cleaning and sorting, water quality, no pesticide residue) should be emphasized and quality standards (sorting and grading) enforced.

### Marketing issues

These should begin with crop value addition after harvest (appropriate packaging, proper drying, appropriate recipe and cooking). Market segmentation should guide pricing and promotion strategies. Proper transportation and distribution channels (proper quality vehicle and refrigerated trucks) as well as promotion to create awareness are still critical issues for marketing of AIVs.

## SUMMARY OF RESOLUTIONS

1. An informal working group was launched and Dr. John Wesonga was nominated to be the moderator of on-line discussion that will be hosted by FAO. Dr. Wesonga will contact Dr. Rémi Nono-Womdim of FAO to work out the modalities of enhancing communication among the members.
2. The next workshop will be held in Abidjan, Cote D'Ivoire in 2010.
3. The next workshop will coincide with World Year of Biodiversity, therefore the proposed theme is "Diversity and Genetic Resources of African Indigenous Vegetables".
4. Dr. Fondio Lassina of Centre National de Recherche Agronomique (CNRA), Abidjan, Cote D'Ivoire will be the coordinator/facilitator of the next workshop.
5. ISHS, Bioversity International and Crops for the Future will be requested to support and co-organize the workshop.

# Workshop Agenda

| Time | Resource Person | Topic |
|---|---|---|
| **Day I (Dec 7, 2009)** | | |
| **Session 1** | **Chair: Olouch Mel** | |
| 0830-0900 | Nono-Womdim Rémi | Introduction |
| 0900-0930 | Abukutsa-Onyango Mary | Good Agricultural Practices for Production of Underutilized Vegetables in Sub-Saharan Africa: Current Status and Future Perspectives |
| 0930-1000 | Seck Abdoulaye | Good Agricultural Practice for the Production of African Eggplant in Sub-Saharan Africa |
| 1000-1030 | Snow Crest | Coffee/Tea Break |
| **Session 2** | **Chair: Abang Mathew** | |
| 1030-1100 | Ochuodho Julius Onyango | Good Agricultural Practices for the Production of Spiderplant in Sub-Saharan Africa |
| 1100-1130 | Fondio Lassina | Good Agricultural Practices for the Production of Amaranth in Sub-Saharan Africa |
| 1130-1200 | Ariyo Omolayo Johnson | Good Agricultural Practices for the Production of Okra in Sub-Saharan Africa |
| 1200-1400 | Snow Crest | Lunch Break |
| **Session 3** | **Chair: Seck Abdoulaye** | |
| 1400-1430 | Agong Stephen Gaya | Good Agricultural Practices for the Production of African Nightshade in Sub-Saharan Africa |
| 1430,1500 | Emongor Vallantino Erone | Good Agricultural Practices for the Production of Moringa in Sub-Saharan Africa |
| 1500-1530 | N'gbesso Mak Francoise De Paul | Good Agricultural Practices for the Production of Jute Mallow in Sub-Saharan Africa |
| 1530-1600 | Snow Crest | Coffee/Tea Break |
| **Session 4** | **Chair: Ariyo Omolayo Johnson** | |
| 1600-1630 | Kusolwa Paul | Good Agricultural Practices for the Production of Vegetable Cowpea in Sub-Saharan Africa |
| 1630-1700 | Oluoch Mel | Good Agricultural Practices for the Production of Pumpkins in Sub-Saharan Africa |
| **Day II (Dec 8, 2009)** | | |
| **Session 1** | **Chair: Agong Stephen Gaya** | |
| 0830-0900 | Woyessa Bulcha | Good Agricultural Practices for Production of Ethipian Mustard in Sub-Saharan Africa |
| 0900-0930 | Hella Joseph Phillip | Economiocs of Production of Underutilized Vegetables in Sub-Saharan Africa |
| 0930-1000 | Abang Mathew Musumbale | Management of Diseaseas and Pests of Underutilized Vegetables for GAP Compliance in Sub-Saharan Africa |
| 1000-1030 | Snow Crest | Coffee/Tea Break |

| Session 2 | Chair: Abukutsa-Onyango Mary | |
|---|---|---|
| 1030-1100 | Oluoch Mel | Nutritional, Antinutrient and Nutraceutical Properties of Underutilized Vegetables in Sub-Saharann Africa |
| 1100-1130 | Mungai Phyllis Muturi | Linking Farmers to Markets and Marketing Systems of Underutilized Vegetables in Sub-Saharan Africa |
| 1130-1200 | Kirenga Geoffrey | Policy Guideliness for Good Agricultural Practices in the Production of Underutilized Vegetables in Sub-Saharan Africa |
| 1200-1400 | Snow Crest | Lunch Break |
| **Session 3** | **Coordinators: Nono-Womdim Rémi, Ojieyo Chris** | |
| 1400-1530 | Groups | Breakout sessions |
| 1530-1600 | Snow Crest | Coffee/Tea Break Africa |
| **Session 4** | **Chair: Nono-Womdim Rémi** | |
| 1600-1700 | Groups | Reports/Wrap-up Discussion from the Breakout Sessions |
| 1700-1730 | Nono-Womdim Rémi | Closing Remarks |
| 1700-1730 | Ojiewo Chris | Wrap up/Announcements |

# List of Participants

| Participant Name | Contacts |
| --- | --- |
| **ABUKUTSA-ONYANGO Mary** | Department Horticulture<br>Jomo Kenyatta University of Agriculture & Technology<br>Thika Road, Juja<br>P.O. Box 62000-00200 Nairobi, Kenya<br>mabukutsa@yahoo.com |
| **HELLA Joseph Phillip** | Sokoine University of Agriculture<br>Dept. of Agric. Economics & Agribusiness<br>P.O. Box: 3007, Morogoro, Tanzania<br>jp_hella@yahoo.co.uk copy to: jhella@suanet.ac.tz |
| **ABANG Mathew Musumbale** | AVRDC-The World Vegetable Center<br>Regional Center for Africa<br>P.O. Box 10, Duluti, Arusha, Tanzania<br>mathew.abang@worldveg.org |
| **OLUOCH Mel** | AVRDC-The World Vegetable Center<br>Regional Center for Africa<br>P.O. Box 10; Duluti, Arusha, Tanzania<br>mel.oluoch@worldveg.org |
| **MUNGAI Phyllis Muturi** | Farm Concern International<br>P.O. Box 15185, Nairobi, Kenya<br>phyllis@farmconcern.org |
| **KIRENGA Geoffrey** | Ministry of Agriculture, Food Security and Cooperatives<br>P.O. Box 9192, Dar es Salaam<br>Tanzania<br>Tel. +255754307814<br>geoffrey.kirenga@kilimo.go.tz; geoffreykirenga@gmail.com |
| **ADUGNA Wakjira** | Breeder, oilseeds<br>EIAR, Holetta Res. Center, Ethiopia<br>adugnawg@yahoo.com |
| **OCHODHO Julius Onyango** | Department of Seed Crop and Horticultural Sciences<br>Moi University<br>P.O. Box 1125 – 30100, Eldoret, Kenya<br>juliusochuodho@yahoo.com |
| **FONDIO Lassina** | Centre National de Recherche Agronomique (CNRA)<br>P.O. Box 1740, Abidjan, Cote D'Ivoire |
| **SECK Abdoulaye** | Concern Universal<br>P.O. Box 2164, 220 Serrekunda<br>The Gambia<br>abdoulaye.seck@concern-universal.org; aseck44@yahoo.fr |
| **ARIYO Omolayo Johnson** | University of Agriculture, Abeokuta<br>P.O. Box 13-11001 Abeokuta, Nigeria<br>ariyojo@yahoo.com |
| **AGONG Stephen Gaya** | Bondo University College<br>P.O. Box 210-4006 Bondo, Kenya<br>sgagong@nbnet.co.ke; sgagong@ymail.com |
| **EMONGOR Vallantino Erone** | Botswana College of Agriculture, Crop Science and Production<br>Private Bag 0027 Gaborone, Botswana<br>v_emongor@yahoo.com; vemongor@bca.bw |
| **N'GBESSO Mako François De Paul** | Centre National de Recherche Agronomique (CNRA)<br>P.O. Box 1740, Abidjan, Cote D'Ivoire<br>infoline@cnra.ci |

| **KUSOLWA Paul** | Sokoine University of Agriculture<br>P.O. Box 3005 Morogoro,Tanzania<br>kusolwa@suanet.ac.tz |
|---|---|
| **SAMALI Silvester** | Horticultural Research and Training Institute-Tengeru<br>(HORTI-Tengeru) |
| **MWAI Gideon Njau** | Maseno University<br>P.O. Box 333-40105 Maseno, Kenya |
| **WESONGA John Mwibanda** | Department of Horticulture<br>Jomo Kenyatta University of Agriculture and Technology<br>P.O. Box 62000-00200, Nairobi, Kenya<br>jwesonga@agr.jkuat.ac.ke |
| **OJIEWO Chris** | ICRISAT-Malawi<br>Chitedze Agricultural Research Station<br>Box 1096, Lilongwe, Malawi<br>C.Ojiewo@cgiar.org |
| **NONO-WOMDIM Rémi** | FAO Plant Production and Protection Division<br>Rome, Italy<br>remi.nonowomdim@fao.org |
| **MWANIKI Phoebe Kirigo** | AVRDC-The World Vegetable Center<br>Regional Center for Africa<br>P.O. Box 10, Duluti, Arusha, Tanzania |
| **SILUE Drissa** | AVRDC-The World Vegetable Center<br>Regional Center for Africa<br>P.O. Box 10, Duluti, Arusha, Tanzania<br>drissa.silue@worldveg.org |
| **JUMA William** | AVRDC-The World Vegetable Center<br>Regional Center for Africa<br>P.O. Box 10, Duluti, Arusha, Tanzania |

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