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Current overview of legume production in the East Africa – challenges and perspectives

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Author: Andrea Maršíčková

Supervisor: Ing. Olga Leuner, Ph.D.

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Andrea Maršíčková

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Cíle práce

The aim of this thesis will be to identify the key challenges facing legume production in East Africa, which include pests, diseases, climate change, soil fertility and market access. The specific aim will be to explore legumes with the highest potential as a food source and income source for smallholder farmers in East Africa and to emphasize the socioeconomic benefits of legume production; additionally, to provide recommendations for improving legume production in East Africa, including strategies for promoting sustainable production practices, improving market access, and enhancing the capacity of farmers and other stakeholders.

Metodika

The species were selected with respect to their distribution, focusing on the eastern part of Africa. For each species, a literature search was conducted from Web of Knowledge, Scopus and JSTOR databases. These sources were supplemented with local grey literature sources (qualifying papers, technical reports). The paper first gives a general overview of the nutritional situation in East Africa and a general overview of legumes. It then provides a characterization of each species (botanical characteristics, ecology) and their importance in traditional local cropping and food systems and assesses their potential to address the problem of malnutrition.

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legumes, intensification, cultivation, East Africa, challenges, perspectives, sustainable agriculture, food security, crop yield, market access, technology, innovation

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prof. dr. ir. Patrick Van Damme

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Declaration

I hereby declare that I have done this thesis entitled Current overview of legume production in the East Africa – challenges and perspectives independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 14.04.2023

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Abstract

This thesis explored the potential of legumes to enhance food security, soil health, and economic development in East Africa. Despite their ability to fix nitrogen, improve soil fertility, and provide nutritional value, legumes have not been fully utilized by smallholder farmers due to various socio-economic challenges. This thesis reviewed current literature on legume production and explored various innovations such as intercropping, improved seed varieties, and integrated pest management, which could improve legume production efficiency and sustainability. The study also examined the policies and programs needed to promote the adoption of legumes by smallholder farmers, including market linkages, seed certification, training, and extension services. Through literature review and case studies, this thesis provided insight into the challenges facing legume production in East Africa and the solutions to promote its adoption. The thesis concludes by emphasizing the need for stakeholders to collaborate and work towards the sustainable production and utilization of legumes in East Africa, in order to enhance food security, improve livelihoods, and promote sustainable agriculture.

Key words: legumes, intensification, cultivation, East Africa, challenges, perspectives, sustainable agriculture, food security, crop yield, market access, technology, innovation

Abstrakt

Tato práce se zabývala zkoumáním potenciálu luštěnin v oblasti východní Afriky pro zvýšení potravinové bezpečnosti, zdraví půdy a hospodářského rozvoje. Luštěniny mají schopnost vázat dusík, zlepšovat úrodnost půdy a poskytovat nutriční hodnoty, ale kvůli různým socioekonomickým problémům je drobnými zemědělci plně nevyužívají. Tato práce se zaměřila na shrnutí literatury o produkci luskovin a její vylepšení. Mezi ně patří pěstování meziplodin, vyšlechtění nových odrůd osiva a integrovaná ochrana proti škůdcům, které by mohly zlepšit efektivitu a udržitelnost produkce luskovin. Dále se práce věnovala zkoumání vládních opatření a programů, které by mohly podpořit zavádění luštěnin u drobných zemědělců, včetně propojení s trhem, certifikace osiv, školení a poradenských služeb. Prostřednictvím přehledu literatury a případových studií poskytla tato práce vhled do problémů, kterým čelí produkce luštěnin v oblasti východní Afriky a ukázala řešení pro podporu zavádění luštěnin. V závěru práce byla zdůrazněna potřeba spolupráce zúčastněných stran a snaha o udržitelnou produkci a využívání luštěnin v oblasti východní Afriky s cílem zvýšit potravinovou bezpečnost, zlepšit životní podmínky a podpořit udržitelné zemědělství.

Klíčová slova: luskoviny, intenzifikace, pěstování, východní Afrika, výzvy, perspektivy, udržitelné zemědělství, potravinová bezpečnost, výnosy plodin, přístup na trh, technologie, inovace.

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List of the abbreviations used in the thesis

Africa RISING – Africa Research in Sustainable Intensification for the Next Generation

BCMV – Bean common mosaic virus

CCMV – Cowpea chlorotic mottle virus

IPM – Integrated pest management

LDL – low density lipoprotein

P – Phosphorus

1. Introduction

The nations of East Africa are grappling with numerous socio-economic and environmental challenges such as poverty, rapid population growth, poor agricultural output, degradation of land resources, recurrent drought, and intense heat waves, resulting in reduced crop yields. Over the past few decades, droughts have triggered widespread famine and economic difficulties across the region (Richardson et al. 2022).

Legumes play a prominent role in addressing malnutrition. They are an important source of protein, minerals, and other nutrients for millions of people around the world, especially in East Africa (Duncan et al. 2019). Despite their many nutritional benefits, legume production in the region faces numerous challenges that hinder its growth and sustainability.

In recent years, there has been an increasing global awareness of the role of legumes in sustainable agriculture and food security. Legumes are known for their exceptional ability to fix atmospheric nitrogen, enhance soil fertility, and increase crop yields in a sustainable manner. In addition, they have a low carbon footprint and are environmentally friendly compared to other crops, making them a crucial component of sustainable agriculture and climate change mitigation (Schipanski et al. 2018).

Despite their many advantages, the production of legumes in East Africa faces numerous challenges, including poor seed quality, lack of access to markets, inadequate infrastructures, limited technical know-how (Amare et al. 2012) and the effects of climate change (Tadele 2018). These challenges have resulted in low productivity and profitability, making it difficult for farmers to invest in legume production.

This thesis provides an in-depth analysis of the status of legume production in East Africa, highlighting the challenges and opportunities that exist in this sector. Through a critical review of the latest research and data on legume production in the region, this study provides valuable insights and recommendations aimed at enhancing the productivity, profitability, and sustainability of legume production in East Africa. The findings of this thesis can contribute to the efforts aimed at addressing the socio-economic and environmental challenges facing the region, with the goal of promoting sustainable agriculture and food security in East Africa.

2. Aims of the Thesis

The aim of this thesis will be to identify the key challenges facing legume production in East Africa, which include pests, diseases, climate change, soil fertility and market access. The specific aim will be to explore legumes with the highest potential as a food source and income source for smallholder farmers in East Africa and to emphasize the socioeconomic benefits of legume production; additionally, to provide recommendations for improving legume production in East Africa, including strategies for promoting sustainable production practices, improving market access, and enhancing the capacity of farmers and other stakeholders.

3. Methodology

The species were selected with respect to their distribution, focusing on the eastern part of Africa. For each species, a literature search was conducted from Web of Knowledge, Scopus and JSTOR databases. These sources were supplemented with local grey literature sources (qualifying papers, technical reports). The paper first gives a general overview of the nutritional situation in East Africa and a general overview of legumes. It then provides a characterization of each species (botanical characteristics, ecology) and their importance in traditional local cropping and food systems and assesses their potential to address the problem of malnutrition.

4. Literature Review

4.1. Dietary status in East Africa

According to FAO (2015) and Ojiewo et al. (2015a), malnutrition caused by imbalanced diets lacking in protein and essential micronutrients such as vitamin A, iron, zinc, and iodine, remains the most devastating issue for many impoverished and needy individuals in Eastern Africa. This situation results in mortality, morbidity, poor mental and physical development, inadequate academic performance, and retarded national socioeconomic development (COHA Report 2013). Furthermore, a society that is malnourished lacks the physical and mental capacity to generate sufficient food for sustenance and must rely on external sources for survival (Ojiewo et al., 2015a).

The importance of consuming a diverse and nutritious diet cannot be overstated, as it is crucial for the well-being and development of individuals, communities, and nations. However, malnutrition remains a significant challenge in East Africa, with high levels of undernourishment and micronutrient deficiencies, particularly among vulnerable populations such as children and women. Legumes, being an important source of protein, minerals, and other nutrients, have the potential to play a significant role in addressing malnutrition in the region (Temba et al. 2016).

4.2. Farming systems in East Africa - introduction

A large proportion of East Africans are subsistence farmers, but farming systems are influenced by a range of factors that can have varying impacts on the integration of legumes into these systems and on their contribution to the functioning of these systems. Among the most obvious pressures is population growth (Josephson et al. 2014). Population density is as high as 500 persons/km2 (Himeidan & Kweka, 2012). This high population density leads to small farm sizes, with most smallholder farmers farming less than 1 ha (Rapsomanikis 2015).

In East Africa, farming systems exhibit diversity, but are commonly distinguished by the combination of crop and livestock production, incorporating cereals, roots, legumes, livestock, and tree crops. Livestock are a key component of the agricultural system in East Africa. Poorer households typically have less livestock, land and labour (Tittonell et al. 2010). These conditions play an important role in integrating legumes into existing farming systems.

Mixed farming systems in East Africa are dominated by staple cereal crops like maize and teff, or starchy roots such as cassava, leading to the underutilization of legumes. While legumes, such as field beans in Kenya and DRC, or lentils in Ethiopia, are present in these systems as grain legume intercrops or relay crops, their usage is limited in comparison to the potential benefits that could be obtained from their increased utilization.

4.3. Legumes

Pulses, the dry edible seeds of legume plants, are globally recognized as staple foods due to their unique chemical and nutritional characteristics (Chelladurai & Erkinbaev 2020).

In the East Africa legumes contribute significantly to the diet of the population. For instance, beans alone in Rwanda supply 65% of the national protein intake and 32% of the energy, while only 4% comes from animal-based protein sources (Kelly 2004). Moreover, these crops can significantly contribute to preserving soil fertility through symbiotic nitrogen fixation, as the use of commercial nitrogen fertilizers is economically challenging in the region. Increasing and expanding grain legume cultivation in East Africa could alleviate malnutrition issues and bring long-term stability to the area (Siddiq & Uebersax, 2012).

4.4. Ethnobotany of the most widely cultivated legumes

Legumes play a prominent role in addressing malnutrition. Some of the common legumes in the subregion have the greatest potential and could save thousands of lives include common bean, groundnut, pigeon pea, soybean, chickpea, cowpea, lentil and faba bean. Rich in protein, oil, and micronutrients such as vitamins, iron, and zinc, these legumes have amino acid profiles that complement those of cereals. When consumed together, their nutritional effectiveness is increased. More than 101 million households grow one or more of the six tropical grain legumes in Eastern Africa (Abate et al. 2012).

There are different types of legumes, classified based on their growth duration, form, and usage. Some are seasonal, while others are perennial. Certain legumes are primarily cultivated for their grains, while others are grown for their leaves. Additionally, some legumes have woody stems while others do not. Six classes were defined: Grain legumes (seasonal and perennial), herbaceous legumes (seasonal and perennial), tree legumes (coppicing and non-coppicing).

Grain legumes are mainly grown for their grains. These include *Phaseolus vulgaris, Cajanus cajan, Vicia faba, Glycine max, Vigna unguiculata* and many others. Grain legumes serve as a significant source of household nutrition while also being traded for cash income. Seasonal grains are restricted to a growth duration of one season (e.g. *Vigna unguiculata*, *Arachis hypogaea*), whereas the perennials grow over multiple years (e.g. *Cajanus cajan*). Herbaceous legumes, cultivated primarily for fodder or improving soil fertility, do not possess woody stems. Forage legumes, on the other hand, may share the same species as grain legumes but have been selectively bred for producing biomass. An instance of this is *Vigna unguiculata*, which has both grain and forage varieties. Many legumes exhibit multi-functionality, like *Lens culinaris* that serve as a source of grain while also being utilized as livestock feed through their straws. Additionally, they play a vital role in crop rotation by improving soil fertility and mitigating disease build up.

4.4.1. *Vigna unguiculata* L.

Cowpea is a member of Leguminosae family native from Africa, serves as a major protein source for millions of individuals in sub-Saharan Africa and other developing regions. The crop is renowned for its exceptional protein quality, high nutritional value, and unique features such as nitrogen-fixing ability and tolerance to drought and heat, distinguishing it from other legume varieties (Steele 1976).

Botanical description

Cowpea V. unguiculata can grow up to 80 cm and up to 2 m for climbing cultivars. It has a well-developed root system. During germination, the first pair of true leaves emerge as simple and opposite, with subsequent leaves appearing as alternate, trifoliate structures that possess oval leaflets measuring 6-15 cm in length and 4-11 cm in width. The papillonaceous flowers are produced on racemose inflorescences at the ends of peduncles, which arise from leaf axils and come in various hues of white, yellowish, pale blue, or violet. Peduncles are stout and grooved, typically much longer than the leaves (2-20 cm long). The flowers emerge sequentially in alternating pairs on thickened nodes at the tip, with cushion-like extra-floral nectaries situated between each pair of flowers. Each flower is sizeable (standard is 2-3 cm in diameter), with a straight keel, diadelphous stamens (one free and nine fused), a sessile ovary containing many ovules, and a style that is bearded along the inside and ends in an oblique stigma. The pods occur in pairs, forming a V shape and are typically pendent and vertical, but can be erect. They are cylindrical in shape, 2-6 cm long and 3-12 mm wide, and contain 8-20 seeds. Seed coloration can vary, with white, pink, brown or black being possible (Heuzé et al. 2013) (Figure 1).

Figure 1: Aerial parts of cowpea (Source: Steward 1958)

Distribution

Cowpeas that are cultivated as warm-season-adapted annuals are grown in tropical and subtropical regions worldwide as classified by Hall (2001), including sub-Saharan Africa, Asia, South America, Central America, the Caribbean, the United States, and areas surrounding the Mediterranean Sea. In subtropical regions, cowpeas can only be grown during the summer due to temperature limitations, while tropical zones provide suitable temperatures all year round. However, most of the cowpea production (over 95%) takes place in sub-Saharan Africa, with about 12.5 million hectares of cowpea cultivated globally in 2014 (Singh et al. 2002). In East Africa, the cawpea is found in Ethiopia, Kenya, Tanzania, Uganda, Zambia, Malawi, Zimbabwe, Mozambique, Rwanda and Burundi (Figure 2).

Figure 2: Distribution of *Vigna unguiculata* (Source: MapChart, Autor 2023)

Utilization

This legume has a versatile use in both human and animal consumption, with its dry grain being the most significant product for human consumption. The grain can be consumed boiled, fried, or steamed (known as moi moi), and can be incorporated into various dishes such as salads, snacks, and cakes. In addition, certain regions of the world also consume the fresh pods, young leaves, and fresh seeds of this legume (Ron 2005; Singh et al. 2003). One of the most important characteristics of cowpea is the high nutritive content value of all plant parts (Ron 2005). The dry grain is a notable source of protein, containing 23-32% of this nutrient. Additionally, it is abundant in essential amino acids like lysine (427 mg g−1 N) and tryptophan (68 mg g−1 N), but relatively low in sulphur-containing amino acids (Fatokun et al. 2002; Timko et al. 2007). The presence of both minerals (iron and zinc) and vitamins (folic acid and vitamin B) has also been reported to be important in preventing birth defects during pregnancy (Nielsen et. al 1993).

Cowpea's ability to thrive in soils with low fertility can be attributed to its capacity to form symbiotic relationships with various microorganisms, including nitrogen-fixing bacteria such as rhizobia and vesicular-arbuscular mycorrhizal fungi (Elowad & Hall 1987). Given cowpea's ability to withstand low fertility soils and adapt to a broad range of soil pH, as well as tolerate high temperatures and drought, this grain legume crop is particularly relevant in addressing anticipated environmental changes such as elevated temperatures and reduced water availability linked to climate change (Hall 2004).

4.4.2. *Lens culinaris* **Medik.**

Lentil (Lens culinaris) is a species of legume plant that belongs to the family Fabaceae. It is an annual food legume, is highly regarded worldwide for its grain. With its nitrogen-fixing capabilities and its high-protein, high-micro-nutrient seeds that are ideal for human diets, and its straw being suitable for animal feed, lentil holds great importance in cereal-based cropping systems.

Botanical description

Plant that grows to a height of 20 to 40 centimetres and has small, lens-shaped seeds that are used as food. The leaves are green and are arranged alternately on the stem. The plant produces small, greenish-yellow flowers that are arranged in clusters on a raceme.

Lentils have small lentil-like seeds (Figure 3) that are used as food. The structure of lentil seed is like that of other legumes (Aykroyd et al. 1982; Salunkhe et al. 1985). The use of scanning electron microscopy to examine five lentil cultivars has revealed their similarity, despite the lentil seed coat being significantly thinner than that of many other food legumes (Hughes & Swanson 1986). The lentil seed consists of three primary constituents: the seed coat, cotyledons, and the embryo, which together account for 8%, 90%, and 2% of the total seed weight, respectively (Singh et al., 1968).

Figure 3: Lentil plant (Source: PROTA 2015)

Distribution

It is commonly believed that lentil originated in the Near East arc and Asia Minor (Singh & Jauhar 2005). From its origin in the Middle East, lentil cultivation spread east through Asia to the Indian subcontinent. The crop also spread into Southern and Central Europe as well as to North and East Africa. Lentil in East Africa is now mainly grown in Ethiopia, Eritrea, South Sudan, Kenya, Tanzania and Malawi (Figure 4).

Figure 4: Distribution of *Lens culinaris* (Source: MapChart, Autor 2023)

Utilization

Lens is consumed worldwide and appreciated for their richness in proteins, dietary fibers, complex carbohydrates, and essential micronutrients such as iron, zinc, and the vitamin B complex (Khazaei et al. 2017, Nosworthy et al. 2017). Besides their remarkable nutritional value, lentil seeds possess a high antioxidant capability compared to other grain legume varieties due to the presence of specific phenolic compounds in their composition (Grela et al. 2017). As a result, lentil consumption has been linked to various health benefits over the years and can help prevent and manage conditions such as cardiovascular diseases, type II diabetes, various cancers, and obesity, among others (Pistollato et al. 2015).

Lentils have traditionally been used in homemade dishes and commercially processed snacks, like fried and extruded products. In recent years, there have been efforts to create lentil-based products using whole or dehulled lentil flour. Some examples include flatbread (Marchini et al. 2021), crackers (Polat et al. 2020), extruded snacks (Ciudad-Mulero et al. 2020), puffed snacks (Guillermic et al. 2021), yogurt with lentil isolates (Benmeziane et al. 2021), and energy bars (Gao et al. 2020).

4.4.3. *Vicia faba* L.

Vicia faba L. is an ancient plant species belonging to the Leguminosae family. In 1991, Faba bean (*Vicia faba* L.) was cultivated on almost 3.2 x 106 ha globally (FAO 1992) and is known as broad bean, horse bean, or field bean. Due to its high nutrient content, it is suitable for human consumption as well as animal feed. The most common use is as human food in developing countries. It is an essential source of protein and other nutrients, particularly in rural areas where meat consumption is low. In addition to its food uses, faba bean has several other applications in East Africa. It is used as a cover crop to improve soil fertility and prevent erosion. The crop is also increasingly being used as a cash crop, as demand for high-quality faba bean seed is on the rise.

Botanical description

Faba bean is an annual herb with a taproot that is long and branched. The plant can grow up to 1-1.5 meters in height, and it has a taproot system that can reach depths of up to 1 meter. The stem is erect, hollow, and ribbed, with branching at the upper parts. The leaves are large and consist of two to six pairs of leaflets that are ovate or lanceolate in shape. The leaflets are smooth or hairy, and they have a dark green color. Faba bean plants produce white or purplish flowers that are borne in clusters on long stalks. The petals are usually large and showy, and they can vary in color from white to pink or purple. Pods are typically 10-20 cm long and 1-2 cm wide. The pods are smooth or hairy, and they contain one to eight seeds each. The seeds are large, flattened, and usually have a white or light brown color, although they can also be green, yellow, or black. (Smartt 1990) (Figure 6).

Figure 5: Flowering and fruiting branch of *Vicia faba* L. (Source: PROTA 2015)

Distribution

Faba bean, which is widely cultivated, is believed to have originated and been domesticated in western Asia, from where it subsequently disseminated to other regions such as Europe, Africa and central Asia. In present times, it is grown extensively in temperate and subtropical regions, as well as at higher altitudes within the tropics (Jarso & Keneni 2006). Although its main presence in tropical Africa is in East Africa, particularly in Ethiopia but also in Eritrea, Uganda, Rwanda, Kenya, Mauritius and Madagascar (Figure 7).

Figure 6: Distribution of *Vicia faba* (Source: MapChart, Autor 2023)

Utilization

Faba beans are a nutritious food source, high in protein, fiber, and complex carbohydrates. They are commonly used in soups, stews, salads, and as a side dish. In some countries, they are ground into flour and used to make bread and other baked goods. Faba beans can also be roasted and eaten as a snack. They are commonly used as a feed for livestock (Huang et al. 2017).

Faba beans are often used as a cover crop to protect the soil from erosion, improve soil fertility, and provide nitrogen to other crops in rotation. Faba beans have the potential to enhance soil fertility, decrease soilborne diseases in potato crops, and promote better soil structure and water penetration in wheat fields. Plants can increase soil microbial biomass and activity, which can benefit the growth of subsequent crops (Huang et al. 2017).

Faba bean accumulates a large amount of L-Dopa in its various parts (Etemadi et al. 2015). L-Dopa, a precursor of dopamine currently used as a major ingredient in treating Parkinson's disease and hormonal imbalance (Inamdar et al. 2013, Hu et al. 2015). Further traditionally used in herbal medicine to treat various ailments, including respiratory problems, digestive disorders, and rheumatism.

4.4.4. *Arachis hypogaea* L.

Groundnut, also known as peanut (*Arachis hypogea* L.) is a significant legume cash crop cultivated by tropical farmers. Groundnut is a self-pollinating allotetraploid legume crop belonging to the *Fabaceae* family (Pasupuleti et al. 2013), is a valuable source of oil (35–56%), protein (25–30%), carbohydrates (9.5–19.0%), minerals (P, Ca, Mg and K), and vitamins (E, K and B) (Gulluoglu et al. 2016). This crop finds application in diverse industries, including food, feed, paints, lubricants, and insecticides (Variath & Janila, 2017). Moreover, groundnut is a suitable crop for rotational systems as it can enhance soil fertility by fixing atmospheric nitrogen naturally (Jaiswal et al. 2017).

Botanical description

Arachis hypogaea L. is an annual that measures about 30–50 cm in height (Figure 7). Its leaves are pinnate and alternate, consisting of four leaflets with no terminal leaflet. The leaflets (Figure 8) are typically 1-7 cm in length and 1-3 cm in width. The plant produces flowers in axillary clusters above ground level, which, after pollination, give rise to a short, thick stem called the gynophore. The gynophore grows downward and penetrates into the soil, causing the entire fruiting body to develop underground. The pods contain one to three seeds each, and each seed is covered with a thin papery seed coat. The plant has a well-developed taproot with numerous lateral roots that can reach a depth of 1-2 meters in the soil, and most of the roots have nodules. The plant prefers light, well-drained, sandy loams, but can also grow in heavier soils (Suchoszek-Łukaniuk et al. 2011).

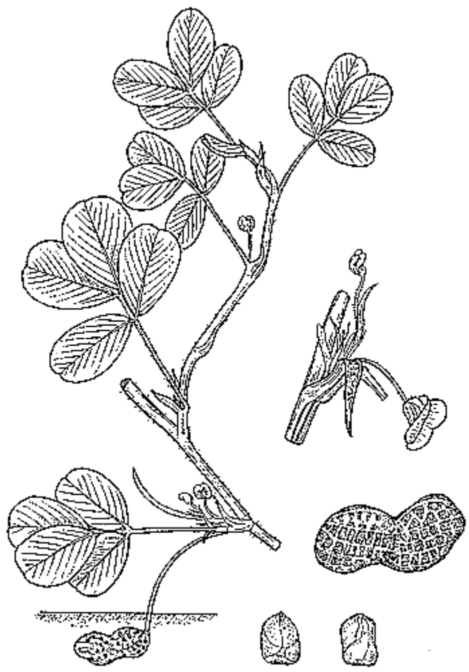

Figure 7: Plant of *Archais hypogaea* (Source: PROTA 2015)

Distribution

Domesticated in Argentina and Bolivia over 3,500 years ago, *Arachis hypogaea* is now widely distributed throughout the world, especially in tropical, subtropical, and warm temperate regions. China, India, and the United States are currently the largest commercial producers of peanuts. Peanuts are cultivated in several East African countries including Kenya, Tanzania, South Sudan, Uganda, Rwanda, and Burundi (Figure 9). Interestingly, peanuts cannot be found in the wild. The plant can thrive in various soil types, including sandy loams, clay loams, and sandy clay soils, but requires a warm climate with sufficient rainfall.

Figure 8: Distribution of *Archais hypogaea* (Source: MapChart, Autor 2023)

Utilization

Groundnut is a significant crop grown in more than 100 countries (FAOSTAT 2010) and is utilized as an important source of oil, food, and feed. The kernels of groundnuts are rich in energy, provided by oil (48-50%) and protein (25-28%), contributing to 564 kcal of energy per 100 g of kernels (Jambunathan 1991). Additionally, groundnut kernels contain a plethora of nutrients such as antioxidants, vitamins, and minerals, and are abundant in mono-unsaturated fatty acids. They are a rich source of biologically active polyphenols, flavonoids, and isoflavones, and contain antioxidants like p-coumaric acid and resveratrol, Vitamin E, and several essential B-complex groups including thiamin, pantothenic acid, vitamin B-6, folates, and niacin, which can enhance human health (UNICEF 2007).

According to Birthal et al. (2010), more than 60% of groundnut production worldwide is crushed to extract oil for both industrial and edible purposes, while 40% is utilized in food and other applications. Groundnut oil is an exceptional cooking medium due to its high smoking point (Singh and Diwakar 1993). Groundnut seeds can be eaten raw, boiled, and roasted, and also used to create confections and flour for baked goods. Additionally, groundnut haulms are a valuable source of fodder for livestock, providing higher levels of protein (8-15%), lipids (1-3%), minerals (9-17%), and carbohydrates (38-45%) than cereal fodder. Cattle digest approximately 88% of crude protein and 53% of nutrients in groundnut haulms, releasing up to 2337 cal kg-1 of dry matter energy. As a legume crop, groundnuts also help to enhance soil health and fertility by depositing N2 and organic matter into the soil (Pasupuleti et al. 2013).

Groundnut is not only nutritionally valuable but also offers various medicinal benefits for human health. It is a good source of monounsaturated and polyunsaturated fatty acids, which have been linked to reducing the risk of cardiovascular diseases by lowering LDL cholesterol levels (Kris-Etherton et al. 2008). Consumption of groundnut has also been associated with improved glycemic control in individuals with type 2 diabetes (Wang et al. 2019). Furthermore, groundnut contains bioactive compounds such as resveratrol, p-coumaric acid, and quercetin that exhibit anti-inflammatory and antioxidant effects, thereby reducing oxidative stress and inflammation in the body. These effects may contribute to the prevention and treatment of chronic diseases like cancer and Alzheimer's disease (Shahidi & Ambigaipalan 2015).

4.4.5. *Phaseolus vulgaris* L.

Phaseolus vulgaris L. is a species of plant in the family Fabaceae. The common bean is a highly variable species, with many different types of beans that differ in size, shape, color, and culinary use. Common beans are a highly nutritious food, rich in protein, fiber, vitamins, and minerals. They are a good source of iron, potassium, magnesium, and folate, and are low in fat and calories. Beans have been shown to have numerous health benefits, such as reducing the risk of heart disease, diabetes, and some cancers. In addition to their nutritional value, common beans also have important environmental benefits. They can fix nitrogen from the atmosphere, which enriches the soil and reduces the need for synthetic fertilizers. Beans are also an important crop for small-scale farmers, as they are relatively easy to grow and can be grown in a variety of soil types and climates.

Botanical description

It is an annual herbaceous plant that grows in warm seasons and has high variability. There are two types of plants: erect herbaceous bushes that can reach 20-60 cm in height, and twining, climbing vines that can grow up to 2-5 m long (Ecocrop, 2013; Smoliak et al., 1990). It has a taproot with many adventitious roots. The stems of bushy types are slender, pubescent and branched, while those of twining types are prostrate for most of their length and rise toward the end (Ecoport, 2013). The leaves, which are trifoliate, are green or purple in color and are borne on long green petioles. Leaflets are 6-15 cm long and 3-11 cm broad. The inflorescences, which are 15-35 cm long racemes, are axillary or terminal. The flowers, which are arranged in pairs or solitary along the rachis, are typically papillonaceous and range from white to purple. Once pollinated, each flower develops into one pod, which can be cylindrical or flat, straight, or curved, and green, yellow, black, or purple in color, sometimes striped. Pods (Figure 10) are typically 1-1.5 cm wide and up to 20 cm in length (Wortmann, 2006) and can contain 4 to 12 seeds. The seeds, which are highly variable in color depending on the variety, are kidney-shaped and range from 0.5-2 cm in length. The two main varieties of seeds are white, red, green, tan, purple, gray, or black, with Kabuli seeds being larger and cream-colored, and Desi seeds being smaller, darker-colored, and either smooth or wrinkled.

Figure 9: Common bean plant (Source: PROTA 2015)

Distribution

The common bean, originally from the Americas, was cultivated by indigenous peoples in Mesoamerica and South America. Later, it was introduced to other parts of the world by explorers and colonizers. Kidney bean is the most popular food legume in Africa, India, Latin America, and Mexico, according to FAO (1993) (Figure 11).

Figure 10: Distribution of *Phaseolus vulgaris* (Source: MapChart, Autor 2023)

Utilization

The health benefits of these beans are numerous, including a reduction in the risk of heart and renal disease (Anderson et al. 1999), a lower glycemic index for individuals with diabetes (Viswanathan et al. 1989), increased satiation (Leathwood & Pollet, 1988), and potential cancer prevention (Hangen & Bennink, 2002). In addition, kidney beans are considered an important source of protein and minerals for livestock feed production, as well as a potential raw material for human food processing (Salunkhe 1982; Gupta 1987).

4.4.6. *Cicer arietinum* L.

Chickpea, also known as garbanzo bean and scientifically named Cicer arietinum L., is an annual herb of the Fabaceae family and is considered one of the oldest grain legume species. With a protein content of 20%–23%, it is a rich source of minerals, fibre, unsaturated fatty acids, and β-carotene (Rizvi & Sarker 2020). It is globally recognized as the third most significant legume and is considered one of the seven founder crops in the Middle East. Chickpea seeds, which are larger and more flavourful than peas, have similar characteristics to peas (Jukanti et al. 2012).

Botanical description

The chickpea plant is a fast-growing, branched herb that can reach heights of up to 1 meter, with a deep taproot that can extend up to 2 meters and numerous lateral secondary roots that explore the upper layers (15-30 cm) of the soil. The stems are hairy, either simple or branched, and can be straight or bent. The leaves are 5 cm long, with 10 to 20 sessile, ovate to elliptical leaflets (Figure 12). Chickpea flowers are typically papilionaceous, and can range in colour from white to pink, purplish, or blue, appearing solitary. The oblong pod is pubescent and inflated, containing 2 or 3 seeds. The size, shape, and colour of the seeds can vary, with diameters ranging from 5 to 10 mm and colours ranging from creamy-white to black (Ecoport 2013; Bejiga et al. 2006).

The two main groups of cultivated chickpeas are the Desi and Kabuli groups. Desi seeds are smaller, darker and have a smooth or wrinkled surface, while Kabuli seeds are larger, cream-colored, and have less fiber, making them preferable for cooking. Desi chickpeas are bushy plants with small leaflets and flowers, with purplish pigments in their stems and blue violet flowers and are mainly grown in Southern Asia and Ethiopia. Kabuli types have upright growth and white flowers and are cultivated in the Mediterranean region (Bejiga et al. 2006).

Figure 11: Plant of chickpea (Source: PROTA 2015)

Distribution

Chickpea, originally from southeastern Turkey (Fehr & Haydley, 1980), is now cultivated in over fifty countries across the world including the Indian subcontinent, Africa, the Middle East, Southern Europe, America, and Australia. In East Africa, it can be found in Ethiopia, Kenya, Tanzania, Eritrea, South Sudan, Uganda, Malawi and Zambia (Figure 13). Chickpea is a legume that thrives in warm and dry regions where other legumes struggle (Houba et al., 2009), and it can grow well on various well-drained soils if its roots can access sufficient moisture (Fehr & Haydley, 1980).

Figure 12: Distribution of chickpea (Source: MapChart, Autor 2023)

Utilization

The demand for chickpeas is on the rise due to their high nutritional value. In regions with semi-arid tropics, chickpeas are a vital component of the diet for those who cannot afford animal protein or are vegetarians. Chickpeas are a great source of carbohydrates and protein, making up around 80% of the total dry weight of the seeds, as per Jukanti et al. (2012) and Singh et al. (2021). Notably, chickpeas are cholesterol-free and provide fiber, protein, vitamins, and minerals, according to Singh et al. (2021).

Chickpeas are environmentally sustainable due to reduced use of synthetic nitrogen, which helps improve soil health, which is one of their significant advantages (Singh et al. 2021).

With a slightly nutty taste, chickpeas are versatile in the kitchen, being used in salads, thick soups, curries, and stews. They can also be blended into sauces, roasted with spices as an appetizer, or ground into chickpea flour, as stated by Dostálová and Kadlec (2014).

4.4.7. *Glycine max* L.

As a member of the Leguminosae family, Soybean (*Glycine max* L.) holds an undeniable position as the most crucial food legume, serving as a primary source of protein and extracted oil.

Botanical description

The soybean, an upright leguminous plant, can reach up to a meter in height, and its taproot can extend to 2 meters deep in favourable soil conditions. The upper 15-20 cm of the soil is explored by its secondary roots, which bear nodules resulting from Bradyrhizobium japonicum infection. The leaves are trifoliate, and the leaflets are generally broad in commercial cultivars, with an oval to lanceolate shape (Ecoport, 2010). The papilionaceous flowers, ranging in colour from white, pink, purple to bluish, have a corolla measuring between 5 to 7 mm in length (Giller et al., 2007). The fruits (Figure 14) are two or three-seeded pods containing yellow, rounded seeds with a hilum ranging in colour from yellow to black, as noted by Koivisto in 2006.

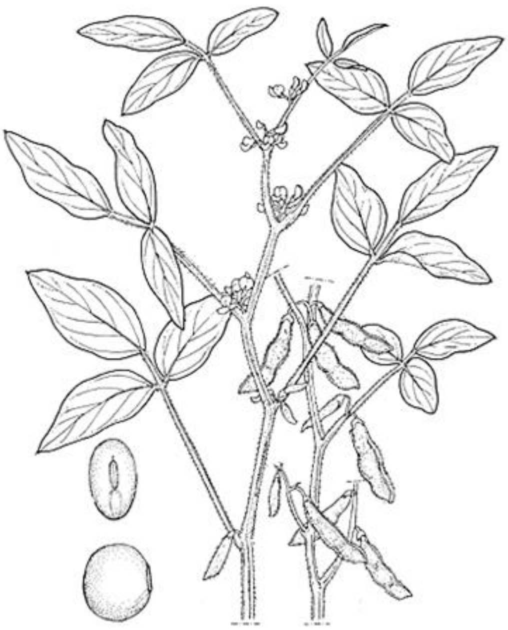

Figure 13: Common Soybean plant (Source: PROTA 2015)

Distribution

Originating from East Asia, Glycine max is a legume species believed to have been domesticated in China, although no precise account of when or where this happened exists (Qiu and Chang, 2010). Presently, the United States stands as the world's leading soybean producer, with Brazil following closely behind, according to the USDA in 2017. Soya bean cultivation has become ubiquitous across the globe, spanning tropical, subtropical, and temperate regions. The crop's tardy expansion beyond Asia can be attributed to the scarcity of soya bean specific rhizobia in non-native soils, with the United States being the first country to adopt the crop in the early 20th century, thanks to scientists' discovery of the nodulation process (Giller & Dashiell 2007). In East Africa they can be found in Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania, Malawi, Zambia, Zimbabwe, Mozambique, Madagascar, Comoros, Mayotte, Reunion and Mauritius (Figure 15).

Figure 14: Distribution of Soybean (Source: MapChart, Autor 2023)

Utilization

The consumption of soybean, which is a major crop legume known as Glycine max L, is prevalent worldwide due to its use as a protein-rich source in various foods and drinks. Despite of proteins it is rich in dietary fibre and a variety of micronutrients and phytochemicals. Soybeans are unique among the legumes because they are a concentrated source of isoflavones (Saito et al. 2003)

Soybean is essential in the production of human food, such as vegetable oil, seed-milk, and tofu, as well as animal feed for chicken and pork, and even biofuel, as highlighted by Gresshoff in 2017. It is useful to make flour, milk, tofu and tofu-like products. It may be roasted and eaten as a snack, or fermented to make tempeh, miso, yuba and soy sauce. Immature soya beans are also eaten as a vegetable, as well as bean sprouts (Giller et al., 2007). Soybean leaves and stems can be grazed, ensiled or dried to make hay. The foliage is very palatable to cattle, has a high nutritive value and is highly digestible (Koivisto, 2006).

Soya bean is a versatile crop with various industrial and commercial applications. Soya bean lecithin act as emulsifiers in the food, pharmaceutical, and industrial sectors, aiding in the production of decorating materials, printing inks, and pesticides. Additionally, soya bean oil is a significant commercial source of natural vitamin E (α-tocopherol) and stigmasterol, which is synthesized to produce steroid hormones and other pharmaceuticals. Soybean seeds and fresh soy milk have been utilized in cosmetic dermatology to enhance skin tone, pigmentation, and photo-aging attributes (Subhasre et al. 2009). The protein extracted from the crop is also used in the production of synthetic fibres, glues, and foams.

Furthermore, the crop can be utilized as green manure, for haymaking and silaging, while the leafy stems left behind after pod removal can be used as fodder (Giller & Dashiell 2007).

4.4.8. *Cajanus cajan* L.

Cultivated for its edible seeds, Pigeon pea (Cajanus cajan L.) is a widely adaptable and hardy tropical and subtropical legume known for its fast growth and drought resistance (Bekele-Tessema 2007). Its ability to thrive in areas with unreliable rainfall and likely droughts makes it an essential crop for ensuring food security (Crop Trust 2014). Additionally, at the end of the dry season, when other forages are scarce, Pigeon pea provides an excellent source of green forage (Sloan et al. 2009).

Botanical description

Pigeon pea, a leguminous shrub, is an erect and short-lived perennial that typically reaches 1-2 meters in height but can grow up to 2-5 meters. It rapidly develops a poisonous taproot that can reach depths of up to 2 meters. The stems are woody at the base, angular, and branch out, while the leaves are alternate and trifoliate (Figure 16), with oblong and lanceolate leaflets measuring 5-10 cm long x 2-4 cm wide. Both the leaves and stems are pubescent. Pigeon pea produces flowers in racemes at the tips or axils of the branches, with 5 to 10 papilionaceous flowers that are usually yellow but can also be streaked with purple. The corolla is about 2-2.5 cm long. The fruit is a flat and straight pubescent pod, 5-9 cm long x 12-13 mm wide, containing 2-9 small, brown, red or black seeds that are occasionally hard-coated (FAO 2016a; Bekele-Tessema 2007).

Figure 15: *Cajanus cajan* plant (Source: PROTA 2015)

Distribution

Having been cultivated for thousands of years, Pigeon pea is believed to have originated in India before spreading to Africa around 2000 BC or earlier. Over time, a secondary centre of diversity emerged in East Africa, where it now grows extensively (Figure 17) (Maesen, 2006). With the spread of conquests and slave trade, Pigeon pea also made its way to the Americas, likely through both the Atlantic and Pacific routes. Although it is now grown throughout the tropics, it remains most significant in the Indian subcontinent and East Africa. Pigeon pea is not known to exist in the wild but can sometimes be found naturalized because of escaping cultivation.

Pigeon pea has become a pantropical and subtropical species that is especially suitable for rainfed agriculture in semi-arid regions due to its fast growth, deep taproot, and heat tolerance (Mallikarjuna et al. 2011). It thrives in temperatures ranging from 20° to 40°C and is frost-free (FAO 2016a). Pigeon pea performs better in areas with annual rainfall exceeding 625 mm, although it can tolerate extended dry periods. It can grow in a broad range of soils, from sandy to heavy black clays, with varying pH levels. However, the optimal pH range is between 5-7, and it has limited tolerance to soil salinity (Duke 1983).

Figure 16: Distribution of *Cajanus cajan* (Source: MapChart, Autor 2023)

Utilization

Cajanus cajan, primarily grown for its edible seeds, is a versatile species that serves various purposes. In Africa, the dried seeds of pigeon pea are commonly utilized to prepare sauces that accompany staple foods like cassava, yam, and rice. The mature seeds are usually fried or boiled, after being soaked or made into porridge. Furthermore, immature pigeon pea seeds and pods are frequently used as vegetables in soups and sauces in several African countries (Phatak et al. 1993).

Cajanus cajan serves a multitude of purposes in animal feeding. Its protein-rich leaves and pods are highly nutritious and palatable fodder. Leaves are sometimes used to replace alfalfa in ruminant diets where alfalfa cannot be grown. Livestock feed is produced from seed processing by-products, and sometimes the whole seeds (Phatak et al. 1993). The seeds are also suitable for poultry consumption. Bees are known to actively feed on pigeon pea, producing a unique, greenish-coloured honey in the comb (Orwa et al. 2009). Pigeon pea is also a good host for lac insects and silkworms (Cook et al. 2005). Plant breeders have developed varieties that are better adapted to drier conditions, more disease-resistant, and well-suited to different production systems and cropping cycles (Valenzuela 2011). Since the 1990s, the number of available varieties has increased, enabling cultivars to be chosen based on not only higher grain yields but also higher forage yields and crude protein (Phatak et al. 1993).

4.5. Benefits of legumes with focus on East Africa

Legumes are distinguished by their ability to enhance soil fertility, achieved through the process of fixing atmospheric nitrogen via symbiotic bacteria in root nodules. Moreover, residual biomass from harvested legume crops can have a favorable impact on the soil's nitrogen levels, benefiting subsequent crops. Increased soil fertility is usually a co-benefit resulting from the production of primary crops such as food or feed (Duncan et al. 2019).

Grain legumes are a crucial source of nutrition for many smallholder families in sub-Saharan Africa, particularly women and children, due to their high nutritional value as the most significant source of protein, calcium, and other minerals and vitamins. In addition to their seeds, the leaves of legumes are also a valuable and nutritious food source, contributing to the overall provision of household nutrition (Duncan et al. 2019).

Legumes, while commonly cultivated for household consumption, can also serve as significant cash crops in East African farming enterprises, generating substantial income through the sale of grains and occasionally fodder (Duncan et al. 2019).

Legumes are an excellent source of feed for livestock, owing in part to their nitrogen-fixing properties that result in higher nitrogen concentrations in their biomass as compared to cereal crop residues, for instance. Given that nitrogen is typically deficient in livestock diets in East Africa, the added nitrogen from legume biomass can greatly enhance livestock productivity. Additionally, nitrogen derived from legume biomass can significantly improve the utilization of poor-quality cereal residues, which serve as the primary basal feed for livestock in East Africa, by supplying nitrogen to rumen microorganisms, thereby promoting more active fermentation in the rumen (Duncan et al. 2019).

Various legumes have demonstrated their efficacy in diminishing soil nutrient and water loss resulting from erosion. Grain legumes, including beans, cowpeas, and green grams, are characterized by their wide leaves, which shield and safeguard topsoil from the impact of heavy rainfall, minimizing nutrient leaching. Furthermore, adding organic matter from legumes to the soil has been demonstrated to enhance its structure and water retention capacity (Duncan et al. 2019).

4.6. Challenges of legumes

Various production and socio-economic constraints, including abiotic and biotic problems, are attributed to the low productivity.

4.6.1. Abiotic factors

Legumes in East Africa face a range of abiotic problems, including drought, soil fertility depletion, salinity, extreme temperatures.

Legumes are often grown in semi-arid regions, where water availability is limited. Drought stress can lead to reduced crop growth, yield, and quality, as well as increased susceptibility to pests and diseases (Omiti et al. 2011).

In some regions of East Africa, soils have high levels of salts, which can negatively affect legume growth and yield. Soil salinity, characterized by a high concentration of soluble salts, affects crop productivity although some indigenous crops have some level of tolerance to this abiotic stress. Chloride and sulphate salts of sodium, magnesium, and calcium are the most common soluble salts. It is estimated that approximately 4.8% of the land in Africa is affected by salinity or sodicity (Tadele 2018). Although salinity occurs due to diverse causes, the main cause of the elevated salinity is the use of highly saline irrigation water in the hot and dry environment where evapotranspiration is high (Geeson 2002).

High temperatures can cause heat stress, while low temperatures can cause cold stress in legume crops, leading to reduced growth and yield. Plants undergo several molecular, cellular, and physiological changes due to heat, with the most significant effects being observed in respiration and photosynthesis, both of which have a substantial impact on crop productivity (Bita & Gerats 2013). Changes in the amount and pattern of the annual rainfall have been negatively affecting the productivity of crops in African countries especially in Ethiopia (Rosell & Holmer 2007). According to the United Nations Food and Agriculture Organization, natural hazards and disasters have a considerable economic impact on vulnerable nations, with the agricultural sector, which contributes up to 30% of the GDP, bearing a significant portion of the burden. Among all agricultural industries, crops are the most vulnerable (FAO 2015).

Legumes have high nutrient demands and are often grown on poor soils, leading to soil nutrient depletion. This can result in reduced crop growth and yield, as well as increased susceptibility to pests and diseases. The level of nutrient depletion in East Africa varies from high to very high, with particularly concerning rates in countries like Kenya, Ethiopia, and Rwanda. Annual depletion rates have surpassed 40 kg N ha^{-1}, 6.6 kg P ha^{-1}, and 33.2 kg K ha^{-1} in these nations (Smaling et al. 1997). The primary reasons for nutrient depletion are land scarcity, intensive cultivation without sufficient nutrient inputs, and water erosion.

The highlands of East Africa, located in the sub-humid zone, have great potential for agricultural production due to their favorable climate and soils. However, in addition to experiencing high rates of nutrient depletion, these highlands are dominated by acid P-fixing soils of the Ferralsols, Acrisols, and Nitisols orders

(Deckers 1993; Sanchez et al. 1997), with phosphorus becoming a significant limiting nutrient for crop production in many of these soils. Although soluble fertilizers are a clear solution to the problem of phosphorus limitation, their application is restricted in small-scale farming systems due to their high cost resulting from inadequate infrastructure. The inadequacy of organic resources to replenish soil phosphorus is evident as they have low P content and availability (Nziguheba 2007).

4.6.2. Biotic factors

Legume crops in East Africa are also affected by various biotic problems, including insect pests, fungal diseases, viral diseases, bacterial diseases and nematode pests.

Legumes are affected by a wide range of insect pests such as aphids, thrips, pod borers, and whiteflies, which can cause significant yield losses and reduce crop quality.

Legumes are susceptible to various fungal diseases, such as anthracnose, rust, and powdery mildew, which can result in reduced growth, yield, and quality.

Legumes can also be affected by viral diseases such as Bean common mosaic virus (BCMV) and Cowpea chlorotic mottle virus (CCMV), which can cause severe yield losses.

Legumes are also susceptible to bacterial diseases such as bacterial blight and crown gall, which can cause significant yield losses.

Nematodes are a significant problem for legume crops, as they can cause stunted growth, reduced yield, and increased susceptibility to other diseases.

4.6.3. Socio-economic issues

In addition to biotic and abiotic problems, legume production in East Africa also faces several socio-economic challenges, including limited access to markets, lack of appropriate technology and knowledge, gender inequality, limited access to credit and finance, dependence on rain-fed agriculture.

Limited market access is a significant challenge for smallholder farmers, as poor infrastructure, inadequate storage facilities, and limited market information can lead to low prices and reduced income. Furthermore, limited productivity in legume crops can also be attributed to challenges in accessing improved varieties resulting from these problems.

Another obstacle is the absence of knowledge regarding advanced legume varieties and comprehensive farming techniques, leading to reduced productivity and income. The promotion and exhibition efforts for these crops are inadequate in comparison to those for staple crops like maize and wheat. The deficiency of understanding among farmers concerning the advantages of modern varieties remains an ongoing issue. In Tanzania, the adoption rate of pigeon pea was notably linked to the knowledge farmers possessed about better varieties (Amare et al. 2012). Similarly, in Ethiopia, the awareness of improved chickpea was closely linked to the adoption rate (Abate et al. 2012).

Women are often marginalized in agriculture and may not have equal access to resources, inputs, and training, which can limit their participation in legume production and income opportunities.

Smallholder farmers may not have access to affordable credit and finance, which can limit their ability to invest in inputs and technologies to improve legume production and increase their income.

Many smallholder farmers in East Africa depend on rain-fed agriculture, which makes them vulnerable to climate variability and drought, leading to reduced crop yields and income.

4.7. Solution

Overall, improving legume production in East Africa requires a combination of agronomic, economic, and policy interventions to address the various challenges faced by farmers in the region.

4.7.1. Water management

Climate change is affecting agricultural production in East Africa, with increased temperatures, changes in rainfall patterns, and more frequent extreme weather events. Farmers can adopt agriculture practices.

East Africa receives significant amounts of rainfall during the wet season. By collecting and storing rainwater, communities can ensure a steady supply of water throughout the year (Barron 2009).

Groundwater is a vital source of water in East Africa, especially in rural areas. Proper management of groundwater resources, including monitoring and regulation of extraction, can help ensure sustainable use. According to Sivakumar (1992), a study conducted in West Africa demonstrated that the occurrence of dry spells within a particular year can be anticipated by examining the annual rainfall of the preceding years. Therefore, this information can be utilized to make informed decisions regarding the selection of crops or cultivars to be grown, as well as the appropriate management practices to be implemented.

Agriculture is a critical sector in East Africa, and irrigation can help farmers grow crops even in dry seasons. Innovative irrigation techniques such as drip irrigation can help conserve water while increasing crop yields.

East Africa has a long coastline, and desalination of seawater can provide a reliable source of freshwater, especially in coastal areas.

Simple measures such as fixing leaks, using water-efficient appliances, and reducing water usage in households and industries can significantly reduce water demand.

4.7.2. Genetic modification

Access to quality seed is critical for successful legume production. Farmers can produce their own seed, but they need access to improved varieties that are adapted to local growing conditions and resistant to pests and diseases (FAO 2017). Governments and NGOs can support the production and distribution of quality seed through seed multiplication programs and the establishment of community seed banks.

Utilizing modern genetic, genomic, and agronomic tools for enhancing indigenous crops can offer significant prospects in ensuring global food security. As per a recent review by Tadele (2014), there exist substantial discrepancies between the average yield of numerous African crops by farmers and their potential yield, indicating the possibility of amplifying crop productivity through advanced cultivars and effective crop management practices.

4.7.3. Soil fertility management

Legumes are nitrogen-fixing crops, which means they can improve soil fertility by fixing atmospheric nitrogen in the soil. However, legumes also require other nutrients like phosphorus, potassium, and micronutrients. Farmers can improve soil fertility by using organic fertilizers, such as compost, manure, or green manure, and by practicing crop rotation to reduce soil-borne diseases and pests.

Conservation tillage, also known as minimum tillage or no-till, is widely used in some parts of the world mainly to control erosion and increase soil fertility. Conservation tillage, leaving the previous year's crop residue on the fields, has the effect of reducing soil erosion and runoff (McHugh et al. 2007).

4.7.4. Tolerance to Salts

Often salinity problems are associated with poorly drained and waterlogged soils as excess water allows the salt to rise to the root zone via capillary action (Barrett-Lennard EG 2003). Once salt has accumulated, only additional water can leach the salts away from the root zone.

To ensure rapid and uniform germination during the seed germination and early establishment stages of plant growth, salt stress needs to be minimized (Ashraf et al. 2008). Enhanced growth can be obtained by immersing seeds in salt solution before sowing. This process is commonly known as “priming.” Priming techniques include osmopriming, halopriming, hydropriming, thermopriming, and hormone priming. Osmopriming utilizes solutions of sugars, glycerol, or mannitol to facilitate germination, while halopriming involves soaking seeds in solutions of inorganic salts such as MnSO4. Seeds are soaked in water before sowing in hydropriming, while high or low temperatures are used for thermopriming. Hormone priming utilizes plant growth regulators like auxin, gibberellic acid, and ethylene (Tadele 2018).

4.7.5. Phosphorus deficiency

The accessibility of soil phosphorus to plants

Plants directly assimilate inorganic P from the soil solution. In the absence of fertilization, the soil solution P is replenished from other soil P pools with varying degrees of availability. The quantity of P reserve required to replenish soil solution P and a soil's ability to maintain an adequate concentration of P in the solution are the primary factors that determine the P supply to plants (Buresh et al. 1997). Buresh et al. (1997) and Mokwunye and Bationo (2002) identified two types of soil P suppliers for plant P: Capital P and Agricultural or Liquid P. Capital P is defined as the stock of soil P that gradually supplies plant-available P and includes sorbed P, a portion of primary P minerals, and P associated with non-labile organic matter. Agricultural or Liquid P refers to the soil P that is available to crops in a single growing season, including P in soil solution and labile P. According to data from several experiments conducted in P-deficient soils in the highlands of East Africa, the inorganic form of Agricultural P, as evaluated by the Olsen method, is less than 5 mg P kg^{-1} soil (Gachengo et al. 1999; Ikerra 2004). The majority of soil P in these soils is in the form of Capital P. Data reported from sequential extraction of NaOH-extractable P, which is presumed to represent a significant portion of Capital P in highly weathered P-fixing soils, ranges from 300–400 mg P kg^{-1} soil (Maroko et al. 1999; Ikerra 2004). Therefore, P deficiency in crops primarily results from limited supply of Agricultural P. Short-term management strategies should focus on increasing Agricultural P, while building up Capital P should be considered a long-term investment for sustainability.

Phosphorus rocks for replenishing phosphorus

The East African region possesses various phosphorus rocks deposits that are regarded as the primary potential resources for phosphorus replenishment (Van Straaten 2002; Buresh et al. 1997). Two categories of deposits exist, sedimentary/biogenic and igneous/residual deposits. The limited sedimentary/biogenic deposits are located in the East African Rift Valley, with the most and largest known deposit at Minjingu in Northern Tanzania (Van Straaten 2002). The igneous/residual PRs are abundant in the region (Van Straaten 2002; Buresh et al. 1997). The highlands' phosphorus-deficient soils are acidic, creating favorable soil conditions for PRs utilization. However, due to their low reactivity, most of these phosphate rocks are qualified for replenishing Capital P but are rarely sufficient as a source of Agricultural P.

Partial acidulation or Compaction with soluble fertilizers

The most employed method to enhance the solubility of P and reduce the expenditure on commercial fertilizers is partial acidulation of PRs. To achieve this, a portion of the necessary sulphuric or phosphoric acid to produce soluble P fertilizers, such as single or triple superphosphate, is applied to the raw or concentrate phosphate rock. This practice is a cost-effective alternative to using soluble fertilizers (Nziguheba 2007).

4.7.6. Intercropping

Simultaneously growing two or more crops during the same season is known as intercropping, and the overall profitability is achieved through sustainable intensification (Brooker et al. 2015). Planting legumes with other crops can help break disease cycles, reduce soil-borne diseases, and improve soil fertility.

Mbili-Mbili – Technology

Mbili-Mbili is a cereal-legume intercropping strategy between cereals and legumes involving three crops with different growth patterns that are spatially arranged within the field. A programme that aims to lift smallholder farming households out of hunger, food insecurity, malnutrition, and poverty. In view of this, the International Center for Tropical Agriculture (CIAT), which is a partner in the Africa RISING project. Program developed and validated legume-based interventions in Babati, Tanzania, amongst which was Mbili-Mbili (Kihara & Kinyua 2022).

The name Mbili-Mbili is derived from the Swahili word "Mbili" meaning two. Dual maize rows alternate with two legume species (Figure 1). Mbili-Mbili uses the spatial configuration of plants to increase luminosity light penetration to legumes that are otherwise often shaded by cereals. Specifically, it focuses on increasing the abundance of pigeon pea and common bean. The Mbili-Mbili technology takes advantage of fast, intermediate, and long growth of beans, maize, and pigeon pea, minimising competition among these crops. Any other crops can be used if they have complementary growth patterns (CIAT 2019).

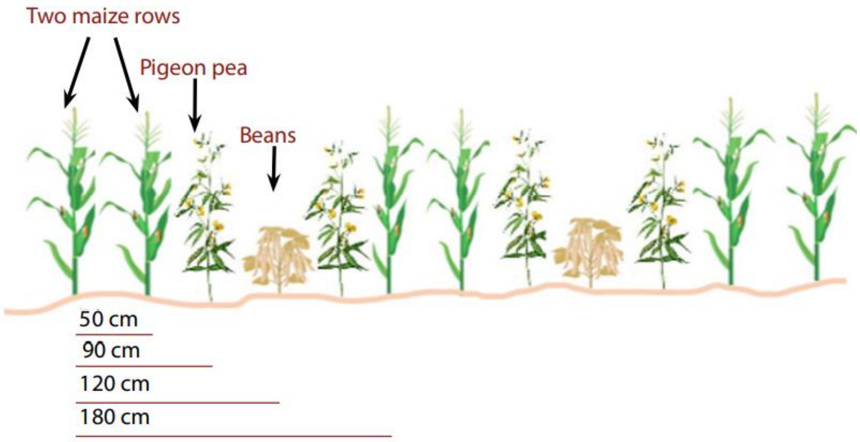

Figure 17: Intercropping of maize, bean, and pigeon pea (Kihara & Kinyua 2022)

In Mbili-Mbili, two rows of maize are planted closer to each other, spaced 50 cm apart, leaving a 130 cm wide space in front of the other two rows of maize, in which two species of legumes with different growth patterns are planted to mimic the Doubled-up method of innovation (Snapp & Silim 2002). Thus, in Mbili-Mbili, a cereal crop and two varieties of legumes, with reduced competition for light, moisture and nutrients for the plants to increase crop yields (Figure 16).

Mbili-Mbili provides staggered harvests over a ten-month growing season, starting with the harvest of beans (0.3 t/ha), maize and later pigeon peas (0.6 t/ha), which ensures food security for farming households. Approximately 80 % of farmers who have adopted the technology perceived it as a benefit positive increase in maize yields of 4 t/ha compared to conventional systems (Kihara & Kinyua 2022).

4.7.7. Integrated pest management

Farmers can use integrated pest management (IPM) strategies to control pests and diseases in their legume crops. This involves using a combination of cultural, biological, and chemical control methods to minimize the use of pesticides and reduce the risk of resistance (Dijkxhoorn et al. 2013).

Integrated Pest Management is a holistic approach to pest management that involves the use of a range of strategies to control pests while minimizing environmental and economic impacts. In East Africa, IPM is increasingly being promoted as a way to address the challenges associated with pest control in agricultural systems (Dijkxhoorn et al. 2013).

IPM strategies include the use of biological control agents, such as natural enemies of pests, and the use of cultural practices that minimize pest damage. This approach also involves the use of chemical pesticides only as a last resort, and then only in a carefully targeted and judicious manner. This helps to reduce the potential negative impacts on human health and the environment, while also helping to prevent the development of pesticide resistance (Dijkxhoorn et al. 2013).

The adoption of IPM in East Africa faces a number of challenges, including limited knowledge and understanding of IPM among farmers and extension workers, inadequate infrastructure, limited access to biological control agents, and the high cost of chemical pesticides. Additionally, the lack of regulation of pesticide use in the region is a significant challenge, with many farmers using highly toxic and banned pesticides that can have serious health and environmental impacts (Dijkxhoorn et al. 2013).

To promote the adoption of IPM in East Africa, there is a need for increased investment in research, training, and extension services. The development of regional networks and collaborations can help to provide access to biological control agents and other IPM resources, and the establishment of regulatory frameworks for pesticide use can help to ensure the safe and judicious use of chemical pesticides. Overall, the adoption of IPM in East Africa has the potential to improve agricultural productivity and sustainability while also reducing negative impacts on human health and the environment (Dijkxhoorn et al. 2013).

4.7.8. Solutions to socio-economic challenges

To address the socio-economic challenges associated with legume production in East Africa, appropriate policies and programs need to be implemented. These should include measures to promote market access, provide training and knowledge sharing opportunities, promote gender equity, and provide affordable credit and finance. While farmers in the region place greater emphasis on the short-term benefits of legumes, including food and income, there is a need to also promote long-term benefits such as natural resource management. In addition to information on pulses, farmers require better market access to procure inputs, sell products, and realize other benefits associated with growing pulses (Muoni et al. 2019).

To improve market access for smallholder farmers, the establishment of market linkages with reliable markets is crucial. This can be achieved through the development of farmer cooperatives that can negotiate better prices and access to credit for their members (Muoni et al. 2019).

Addressing poor seed quality is also important, and investment in the production of high-quality seeds through the development of seed production systems and seed certification programs can help to achieve this goal (Muoni et al. 2019).

Investing in infrastructure such as roads, storage facilities, and processing and packaging facilities can help to address the issue of inadequate infrastructure (Muoni et al. 2019).

Moreover, providing training and extension services to smallholder farmers can help to improve their technical know-how, leading to increased productivity and profitability (Amare et al. 2012).

5. Conclusions

In conclusion, legumes were found to have the potential to contribute significantly to food security, soil health, and economic development in East Africa. Various innovations such as intercropping, improved seed varieties, and integrated pest management were identified as means of making legume production more efficient and sustainable, while also providing additional benefits such as nitrogen fixation and soil fertility improvement. Despite the numerous benefits of legumes, socio-economic challenges such as poor market access, inadequate infrastructure, and limited knowledge and understanding of legume production have remained major barriers to their widespread adoption. However, appropriate policies and programs such as market linkages, seed certification, training and extension services were identified as potential solutions to address these challenges and promote the adoption of legumes by smallholder farmers in the region. It is important that all stakeholders, including policymakers, researchers, and farmers, work together to promote the sustainable production and utilization of legumes in East Africa, in order to realize their potential for enhancing food security, improving livelihoods, and promoting sustainable agriculture.

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