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Pest and diseases in *Moringa* spp.: non-invasive plant protection methods in Ethiopia

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Pest and diseases in *Moringa* spp.: non-invasive plant protection methods in Ethiopia 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 14.4. 2023

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Kateřina Mašková

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Abstract

Moringa stenopetala (Barker f.) Cufod. and *Moringa oleifera* Lamk. are two species of the genus *Moringa*, which have gained increasing attention for their nutritional and medicinal benefits. These trees are native to Africa and India, where they have been traditionally used for food or medicine. However, they are susceptible to various pests and diseases, which can reduce their yield and quality. In recent years, in Ethiopia has been growing interest in developing non-invasive plant protection methods for moringa trees, which can minimize the use of synthetic pesticides and promote sustainable and affordable farming practices. This literature review summarizes the potential of natural plant extracts, biocontrol agents, and cultural practices to control pests and diseases in moringa cultivation. One of the main pests that affect moringa trees is the *Noorda blitealis*, which feeds on the developing leaves, flowers or buds and can cause significant yield losses. Several botanical extracts, such as tobacco or neem oil, together with biopesticides, have been shown to have insecticidal properties against the *N. blitealis*. Moringa trees are also susceptible to various diseases, including *Alternaria* leaf spot, brown leaf spot or *Diplodia* root rot. Several non-invasive plant protection methods such as biopesticides on *Bacillus* spp. bases have been shown to have antifungal properties against these diseases. In addition, cultural practices, such as weeding and plant density, can help to reduce the incidence of these diseases. While these non-invasive plant protection methods show promise, more research is needed to evaluate their efficacy and optimize their use in moringa cultivation. It is also important to develop integrated pest management strategies that combine multiple non-invasive methods to control pests and diseases in a sustainable and effective manner. In conclusion, *M. stenopetala* and *M. oleifera* are valuable crops for their nutritional and medicinal benefits. Non-invasive plant protection methods, such as natural plant extracts and biocontrol agents, offer a promising alternative to synthetic pesticides, but further research is needed to optimize their use. The area of diseases and pests of these woody plants is still very poorly researched and there is certainly scope for research directly in the agricultural land areas of Ethiopia.

Key words: Moringaceae, sustainable agriculture, Africa, drumstick tree, cabbage tree, *Noorda blitealis*, integrated pest management

Abstrakt

Tato literární rešerše je zaměřena na dva nejčastěji pěstované zástupce rodu *Moringa*: *Moringa stenopetala* (Barker f.) Cufod. a *Moringa oleifera* Lamk. V posledních letech získávají stále větší pozornost pro své nutriční kvality a léčivé účinky. Tyto stromy pocházejí zAfriky a Indie, kde se tradičně používají jako potravina a lék. Jsou však náchylné k různým škůdcům a chorobám, které mohou snižovat jejich výnos a kvalitu. V posledních letech roste v Etiopii zájem o vývoj neinvazivních metod ochrany, které mohou minimalizovat používání syntetických pesticidů a podpořit udržitelné a cenově dostupné zemědělské praktiky. Několik studií se zabývalo potenciálem přírodních rostlinných extraktů, biologických kontrolních látek a kulturních postupů pro kontrolu škůdců a chorob při jejich pěstování. Jedním z hlavních škůdců, kteří napadají tyto rostliny je *Noorda blitealis*, která se živí mladými listy, květy nebo pupeny a může způsobit značné ztráty na výnosech. Bylo prokázáno, že několik rostlinných extraktů, jako je neemový olej nebo výtažky z tabáku spolu s biopesticidy, mají insekticidní účinky proti tomuto škůdci. Stromy moringy jsou také náchylné k různým chorobám, včetně alternariové skvrnitosti listů, hnědé skvrnitosti listů nebo diplodiové hnilobě kořenů. Bylo prokázáno, že několik neinvazivních metod ochrany, jako jsou biopesticidy na bázi *Bacillus* spp., mají proti těmto chorobám antifungální účinky. Kromě toho mohou ke snížení výskytu těchto chorob přispět kulturní postupy, jako je plení či hustota výsadby rostlin. Ačkoli se tyto neinvazivní metody ochrany rostlin jeví jako slibné, je zapotřebí dalšího výzkumu k vyhodnocení jejich účinnosti a optimalizaci jejich použití při pěstování. Je také důležité vyvinout strategie integrované ochrany proti škůdcům, které kombinují více neinvazivních metod pro udržitelnou a účinnou ochranu. Neinvazivní metody ochrany rostlin, jako jsou přírodní rostlinné extrakty a bio kontrolní látky, nabízejí slibnou alternativu k syntetickým pesticidům. K optimalizaci jejich využití je však zapotřebí dalšího výzkumu. Oblast chorob a škůdců těchto dřevin je stále velmi málo prozkoumána a je zde zcela jistě prostor pro výzkum přímo v zemědělských oblastech Etiopie.

Contents

List of tables

List of figures

List of the abbreviations used in the thesis

DM	Dry mass
GDP	Gross domestic product
GM	Genetically modified
ICRAF	The International Centre for Research in Agroforestry
IPM	Integrated Pest Management

1. Introduction

Moringa stenopetala (Barker f.) Cufod. and *Moringa oleifera* Lamk., Moringaceae, tropical and subtropical perennial species, these days cultivated almost in every continent of tropical and subtropical part of the world, enjoys considerable popularity. They originate in India and East Africa (Price 1985). *M. stenopetala* and *M. oleifera* have multiple uses (Seifu 2014). Almost every part of this plant is used for human sustenance. Moringa is part of the diet of millions of people in Africa and Asia, and serves as a medicine, water purifier or as a plant preventing erosion or increased evaporation of water from the landscape (Mekonnen 2002; Chadza 2012). Thanks to the natural resilience of this crop, it can be cultivated in diverse range of climate and agroecological zones (Palada 2019).

On the world stage, *Moringa oleifera*, a species native to areas of India, is predominantly cultivated. In Ethiopia, where *Moringa stenopetala* is native, both *M. stenopetala* and *M. oleifera* are currently cultivated (Bartíková et al. 2020). For example, the climate in Ethiopia allows both species to thrive, but growing a non-native moringa specie brings a lot of disadvantages. One of the negatives may be the abandonment of traditional and indigenous *M. stenopetala* cultivation in near future or the import of diseases and pests from areas in India to Ethiopian lands.

In appropriate and natural conditions, these plants are very resistant to pest and diseases. However, since it is grown on almost all continents and not in completely natural habitats, where the climate and other elements differ from the original environment, these plants are susceptible to various pests and diseases (Grace et al. 2020). In the past, the plant protection measures consisted mainly of chemical methods, primarily in developed countries. In the less developed ones, where pesticides are financially unaffordable, the plant protection was dealt by non-invasive protection way, which can be found there to these days (Mridha & Barakah 2017; Sagona et al. 2020). These non-invasive plant protection methods were closely monitored, and many advantages of their use were revealed in comparison to the conventional chemical ones. In less developed countries, care is taken to preserve the original practices of non-invasive plant protection methods and new methods are devised (Mridha & Barakah 2017).

In this thesis, two mostly cultivated types of Moringa in Ethiopia, *Moringa stenopetala* and *Moringa oleifera*, will be discussed and ways of their cultivation will be described. Common pests, and diseases of the genus will be introduced together with non-invasive plant protection methods targeted on Ethiopia.

2. Aims of the Thesis

The goal of this thesis is to summarize information and expertise on known pests and diseases on *Moringa stenopetala* (Barker f.) Cufod. and *Moringa oleifera* Lamk. The thesis aims to describe non-invasive plant protection methods used in *Moringa* spp. cultivation and describe the most appropriate methods of non-invasive control against the most common pests in Ethiopian agriculture. The objective is to create a comprehensive text that could provide a necessary summary of expert knowledge which could be used in future studies focusing on pest and diseases in moringa trees in Ethiopia.

3. Materials and methods

For this thesis, most of the information was gained from scientific papers found through databases such as Web of knowledge (http://apps.webofknowledge.com), Google Scholar (https://scholar.google.com/) or Scopus (http://www.scopus.com/home.url). These sources were followed by reviewing several scientific books, ICRAF internal papers, as well as BSc., MSc. and PhD. theses focused mainly on plant protection, diseases, and pest of *Moringa oleifera* and *Moringa stenopetala* in Ethiopia. All sources are listed in 'References'.

4. Literature Review

4.1. Ethiopia

The Federal Democratic Republic of Ethiopia is situated in the Horn of Africa. The capital city of Addis Ababa, located in the central part of the county, is one of the fastest economically growing cities in this state and one of the fastest growing cities on the continent. Ethiopia is a landlocked country which shares borders with another six African states: Kenya, Somalia, Eritrea, Djibouti, South Sudan, and Sudan. Ethiopia is large state, having total of 1.100.000 square kilometres and has around 113.5 million inhabitants. It is the second most populous country in Africa, in global terms, Ethiopia ranks 12th. Ethiopia is considered as the cradle of mankind, from where modern man made his way to the Middle East and into Europe, later the world (Milkias 2011a; Marcus et al. 2018).

This country is also home for countless numbers of endemic species of mammals, birds, and plants. Today, Ethiopia is struggling with the extinction of wild animal and plant species. Wildlife populations and their natural habitats are being destroyed by human activity (Tesfaye et al. 2018).

Nikolai Vavilov, who identified centres of origin of groups of wild or domesticated organisms in 1940, described Ethiopia as one of the world centres of origin, together with India, Indonesia, and others. Ethiopia is part of the Abyssinian Center, which gave mankind wheat, barley, sorghum, coffee, okra, millet, and many other crops important for human survival (Milkias 2011a). For the last century, this country has been struggling with extensive deforestation. The Ethiopian government is trying to educate the local population and invest in programmes to save native species of plants and animals, also the original living environment. Furthermore, the government is trying to implement non-invasive and ecological ways to entire agriculture; especially they are trying to focus on sustainable cultivation of crops, living environment and plant nutrition and protection (Devereux & Guenther 2007).

4.1.1. Climate and agroecological zones

Ethiopia has several climate zones, even though it is located near the equator and practically the entire surface of the country belongs to tropical climate zone, the height of the terrain greatly influences the climate. Average elevation is 1 330 meters above sea level making Ethiopia one of the highest elevation countries in the world, according to World Data (World Data 2022). In this country you can find relatively diverse range of agroecological zones with specific climate types. From lowland rainforests to relatively cool plateaus. Thanks to these specific climatic conditions, Ethiopia can grow very diverse range of subtropical, tropical crops and even temperate zone crops. Temperature, height, and length of growing period play very important role in local agriculture (Milkias 2011b; Funk et al. 2012).

Historically, Ethiopia had traditional way how to describe and classify individual zones. At the present time, inhabitants and farmers are using those traditional methods of describing agroecological zones of their own land (Figure 1.). This classification contains basic 6 zones (Mulugeta et al. 2006; Lelago et al. 2016):

- Bereha
- Kolla
- Woina
- Dega
- Wurch
- Kur

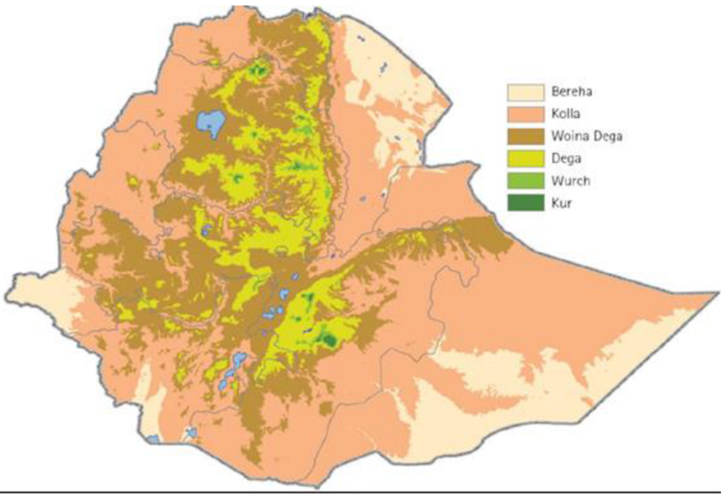

Figure 1. Map of agroecological zones of Ethiopia, (Mulugeta et al. 2006)

4.1.2. Economy and agriculture

More than half of Ethiopia´s gross domestic product (GDP) is generated by agriculture. As a landlocked country, inhabitants cannot make a living from fishing, as in African countries with a seacoast. This is one of the reasons why agriculture plays a vital in Ethiopia. Figures from 2019 and 2021 by The World Bank indicate that about 37% of GDP (The World Bank 2019; The World Bank 2021) is produced by agriculture and overall agriculture employs about 67% of Ethiopia´s population (The World Bank 2019). Agriculture remains the state economy´s most important sector. Regarding livestock, Ethiopia is considered to have the highest number of livestock per capita in Africa. A significant part of the income from the export of products is generated by the sale of live animals or leather. Agricultural production in the state is predominantly subsistence in nature. Only a small percentage of cash crops or agricultural produce is sold abroad for profit. The most important export crop for the country is undoubtedly coffee and corn. Other crops grown are mainly fruit and vegetables, pulses, oilseeds, cereals, potatoes, sugar cane et cetera (Westphal et al. 1975). In addition to above mentioned plant species, teff, okra and sorghum are very important sources of livelihood for the people of the state. Almost all agriculture and especially crop production is in the western part of the state.

This primarily affects the terrain of the state. Up to 70% of the water sources are in the western side of the state and due to mountains, most rivers flow westward (Yigezu 2021).

Thanks to the diverse climate and relatively fertile soil that covers practically the entire state area, the agricultural potential is excellent along with a large labour force. Despite all these positives, agriculture in the state faces a rather serious problem, namely that agriculture is underdeveloped. It is still possible to encounter obsolete agricultural machinery, weak infrastructure, and manual labour (Devereux & Guenther 2007).

In recent years, farmers have faced a much more severe problem, and that is climate change. Increasingly frequent and prolonged droughts deprive farmers of a significant part of their harvest. These prolonged droughts and soil degradation are most likely the result of very intense deforestation. Currently, the government is trying to educate the people of the country and show them the benefits that trees and forests bring to them and prove to farmers that the solution is not always to cut down the forest and established plantations, but that it is possible to create plantations in the forests and practice so-called agroforestry (Devereux & Guenther 2007; Dorosh & Rashid 2013).

4.1.3. Brief cultivation history of *Moringa* spp. in Ethiopia

Moringa stenopetala is a native African specie. It has been used by local people since ancient times for its versatile properties and local farmers have been cultivating these trees since time immemorial. To this day, it is not known exactly when the domestication process of these trees began. Currently, only small populations of the native, non-domesticated species of *M. stenopetala* are found in Ethiopia on the shores of lake Turkana and around the watercourses leading to the lake (Mekonnen 2002). On the other hand, *Moringa oleifera*, non-native, is a species that is more resistant and grows significantly faster, than its relative *M. stenopetala.* It is therefore becoming a major competitor in Ethiopia and rest of the African continent. Even though their cultivation methods in Ethiopia differs in its history, cropping systems of these two plants are almost the same (Price 1985; Ponnuswami 2016).

Historically, crops in Africa were grown on terraced fields. According to historical records, it has been established that as early as the Palaeolithic. People were able to build terraced fields, which had several functions. They served people not only as land for growing crops, but also as places that provided them safe living environment. The high terraces protected them from the hight temperatures, the sun and even the predators that were found in the lowlands. Individual terraces could reach heights of up to 750 metres above sea level (Al & Jahn 1991). In addition to lower temperatures, these terraces provided sufficient moisture for growing crops. In Ethiopia, as in the rest of Africa, this method of farming has had a long history and has become a traditional way of cultivating the land. On these terraced fields, annual crops were grown, but also versatile trees such as *M. stenopetala.* This method of terraced farming in Ethiopia essentially disappeared in 1897 after the Amharic invasion. Europeans were first to reach the inaccessible mountainous areas and thus had the opportunity to see for the first time the species diversity of the individual fields. The first photograph of the *M. stenopetala* was taken by the German photographer Nowack back in 1938. Since then, the *M. stenopetala* has started to be much more cultivated crop in the rest of African continent (Al et al. 1986; Al & Jahn 1991).

The cultivation of *Moringa oleifera* does not have a long history in Ethiopia and throughout Africa. Cultivation of the indigenous species of *M. stenopetala* predominated for many decades. It is only in recent years that the cultivation of *M. oleifera* took place in Africa. This tree has many better characteristics than the indigenous specie and therefore, its commercial cultivation is currently higher (Al & Jahn 1991).

Moringa spp. cultivation methods practiced in Ethiopia are most often system related to cultivation with other crops or livestock. These are mainly agroforestry systems, agri-silvi-horticulure systems, intercropping systems or alley cropping systems. Over the last few decades, as *Moringa* spp. cultivation has intensified, and mainly monocultures can be found in Ethiopia. Monoculture method of cultivation makes these plants significantly more susceptible to various pathogens. At the same time, pests multiply very easily and quickly in these types of environments (Al & Jahn 1991).

Planting of these trees is most often done in two simple and common ways. The first is planting from seed, which is planted at varying densities (depending on the cultivation method chosen) directly into the soil. There is also the option of planting seeds in planters and later planting the grown seedlings in the chosen location on the plot. The second option is vegetative propagation, where young woody branches are rooted in water or directly in the soil (Chadza 2012). Propagation and growing plants from seed is advisable if there is sufficient seed amount and, above all, moisture. The soil should not dry out during germination, but at the same time should not become waterlogged. On the other hand, it is inappropriate to use young, green branches for propagating cuttings. Branches that are already woody and just after harvesting the fruits must always be selected. Plants grown from cuttings grow faster and can develop a very extensive root system in a short time. When propagated by cuttings in a nursery, the plants often develop more slowly than when planted in open soil. The root system develops much more slowly, and the overall growth is limited. Cuttings can be transplanted from the nursery to the open soil after two to three months (Westphal et al. 1975; Ponnuswami 2016).

4.2. *Moringa* spp.

These plants are native to areas of African, Arabian and the Indian subcontinent. In addition to its name moringa, one can also encounter the name drumstick tree, for *Moringa oleifera*, and cabbage tree, for *Moringa stenopetala*. The great advantage of this crop is undoubtedly the fact that it is exceptionally resistant to droughts and temperature variations (Jiru et al. 2006). In the nature it can be found in very diverse sizes, as very small shrubs to large trees, which can be also called pachycaul trees. These pachycaul trees may be described and characterised as trees with very thick and height trunk, with few branches. As a representative of this marked difference between the size of individual species in one genus may be mentioned *Moringa pygmaea*, native to Somalia, which has only 15 centimetres in height when mature. On the other side it stands *Moringa ovalifolia,* or *Moringa stenopetala,* which can reach hight up to 10-12 meters (Habtemariam 2017).

4.2.1. Taxonomy of *Moringa* spp.

The *Moringa* plant is sole woody genus belonging to *Moringaceae* family, which comprises approximately 13 tropical, or subtropical species, which can grow in diverse tropical and subtropical climates and altitudes (Al et al. 1986; Habtemariam 2017). The hierarchy of taxonomy is as follows:

- **Kingdom** Plantae
- **Subkingdom** Tracheonionta
- **Superdivison** Spermatophyta
- **Division** Magnoliophyta
- **Class** Eudicots
- **Subclass** Rosids
- **Order** Brassicales
- **Family** Moringaceae
- **Genus** *Moringa*

Historically, *Moringa* genus has been classified in the order Capparales due to their morphological characteristics. Today it is classified in the order Brassicales, based on evolutionary relationships (Habtemariam 2017).

It can be also subdivided into 4 main categories, sarcorhizal trees, slender trees, bottle trees and tuberous shrubs. Category of tuberous shrubs include species *M. borzhiana, M. longituba, M. pygmaea* or *M. rivae.* Those moringa shrubs are not commercially cultivated, but their tubers are harvested from the wild and have wide use in traditional medicine or can be used to treat intestinal disorders of life stock, most often camels, goats, and cattle (Mallenakuppe et al. 2019).

4.2.2. Moringa stenopetala (Barker f.) Cufod.

Today, *Moringa stenopetala* is distributed in every part of tropical and subtropical Africa. It is not widely known and propagated in such a quantity as its close relative, *Moringa oleifera* (Lalas el al. 2003). It is a multipurpose tree, native and endemic to lowlands in the East Africa, probably to area, where Ethiopia, Somalia and Kenya are located. It can also be called “Cabbage tree” and “African moringa”, and it is commonly grown in private gardens, as well as in fields and plantations (Habtemariam 2017).

It could be cultivated up to 1.800 meters above sea level (Němec et al. 2020) and could resist temperature fluctuations and long periods of drought. Wild trees of *M. stenopetala* can be found in many specific habitats, even though extant populations of these trees are badly documented (Al & Jahn 1991). Those habitats may differ by its climatic conditions and elevation, where an altitude of 1000-2,100 meters above sea level may occur (Seifu 2014), mean annual temperature may differ from 24-30° Celsius and mean annual rainfall ranges between 500-1,400 mm. This plant also has no significant soil requirements. It thrives in almost all soil types but does not tolerate waterlogged and wet habitats with poor drainage. It also has no specific soil pH requirements but thrives best in neutral levels (Seifu 2014).

Widely cultivated are especially in Ethiopia and other African countries where there may be dozens of individuals on the plantation, or they can be planted at lower densities in smaller fields in agroforestry form. It has long been assumed that this plant is not susceptible to pathogens (Price 1985; Melesse 2011; Němec et al. 2020).

The botanical description is very similar for all moringa species. *Moringa stenopetala* is a perennial, sometimes deciduous, or evergreen tree, commonly growing to a height of 6-12 metres. However, it is possible to find individuals that can reach heights of up to 15 metres. The trunk is caudiciform, considerably broad at the base and unusually massively branched in the crown. The trunk can be up to one metre wide at the base. During the dry season, it serves as a water reservoir(Habtemariam 2017; Ebenezar et al. 2020).

The bark of these trees is whitish, silvery to light grey, smooth and massive. Natural peeling of parts of the bark can also occur. Under the bark is soft, light-coloured wood that is full of channels with sticky enzyme myrosin. The crown is massively branched (Figure 2.). The younger branches are characterised by dense, velvety hair caused by trichomes (Habtemariam 2017).

The colour of the leaves is light to dark green when mature. Individual leaflets can be up to 5 centimetres long and the leaf itself can be up to 55 centimetres long. The leaves are alternately attached to the stem by short petioles. They are two- or three- fold, have about five pairs of petioles and three to nine petals on each petiole. The leaf base of some species may have extrafloral nectaries (Al & Jahn 1991).

M. stenopetala has rich, strongly aromatic inflorescence arranged in dense panicles that can be 40-60 centimetres long. The flowers are often radially symmetrical, five-petalled and bisexual. The flowers are relatively small, ranging in size from 1-3 centimetres. It is a plant that blooms in natural conditions from February to April. However, it has been recorded flowering all year round. Pollination is done most often by insects, but also by birds. The calyx of these plants is open, i.e., polyseptate with 4-7 millimetres long sepals. The colour of the calyx, and therefore of the flowers themselves, can range from soft white, cream to slightly pinkish. The flower crown is often polypetal, usually white to light green is the most common colour. Each flower usually has five stamens with white 4-7 millimetres long filaments and yellow 2 millimetres long anthers. The ovary of these flowers is often densely pubescent and drooping, usually 2 millimetres long. The shape of the ovary is most often oval and becomes a smooth cylindrical stamen without stigmatic lobes (Habtemariam 2017).The fruits are oblong-shaped capsules that can range from 10 to 50 centimetres long and 1 to 5 cm wide. The maturation period pf the fruit can be around three months.

In the early stages of fruit growth, pods are twisted, and torses may be present around their seeds. The colour gradually changes from light green to reddish or brown. At maturity, the fruits burst spontaneously, so they are dehiscent. A relatively large number of seeds are released. The colour is usually light brown. The seeds also have wings, which serve to carry the fruit by wind. The seed kernel is most often grey or yellowish (Price 1985; Habtemariam 2017).

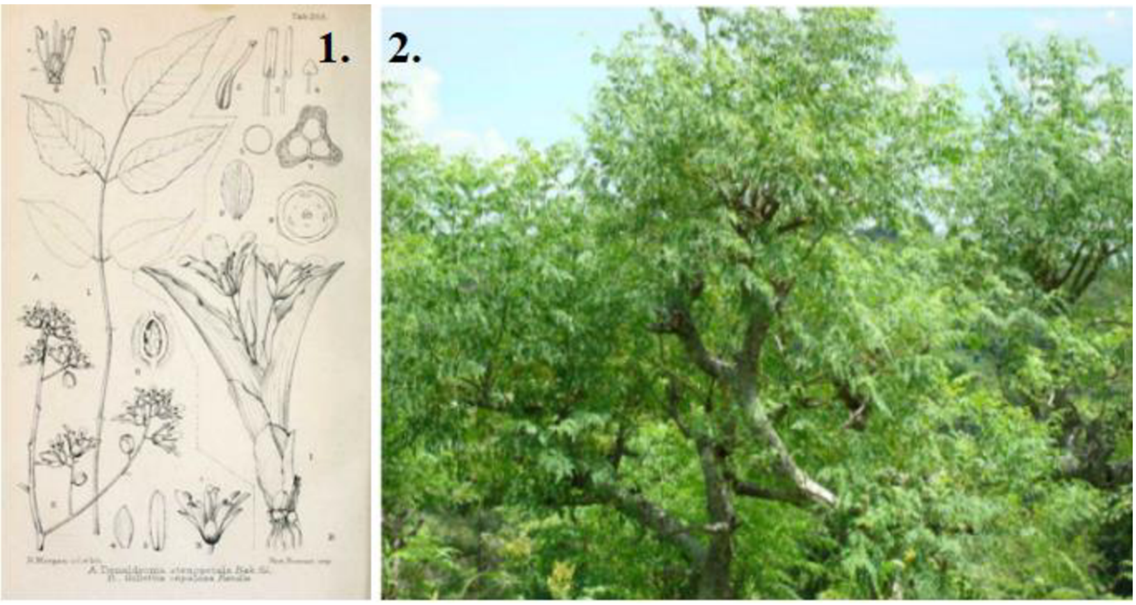

Figure 2. First ilustration of *M. stenopetala* (left side of the figure "1." (Morgan R. 1896)**) and *M. stenopetala* in southern Ethiopia** (Seifu 2014, ICRAF 2014 **"2.").**

4.2.3. *Moringa oleifera* Lamk.

The best-known specie of moringa is certainly *Moringa oleifera.* Its original area of distribution is the Indian peninsula. It occurs naturally from the southern foothills of the Himalayas, where it can grow up to altitudes of around 2.000 metres, to lowlands (Ramachandran et al. 1980). In literature, we could find synonymous names for this plant, such as horseradish tree, drumstick tree or ben oil tree. It has expanded considerably in recent years and has been introduced to almost all parts of the tropical a subtropical world. It is cultivated in large quantities mainly in tropical parts of Asia, Africa, northern South America, Oceania, and Madagascar. Smaller plantations can also be found, for example, in Mexico and Hawaii (Pandey et al. 2011).

It is not demanding in terms of soil composition. It can survive in all types of soil but does not tolerate wet to waterlogged, muddy habitats. It clearly prefers sandy soils. These moringa species require direct sun and can survive in arid areas where annual rainfall is only about 250 mm. By using underground tubers, it can overcome even prolonged periods of drought. Depending on the season and local meteorological conditions, it is an evergreen or deciduous tree. It sheds its leaves during prolonged periods of drought and for a limited period can survive frost during winter months (Price 1985; Pandey et al. 2011; Chadza 2012; Ponnuswami 2016; Sagona et al. 2020).

This moringa specie is cultivated mostly for its leaves and fruits. In many East Asia states, as Indonesia or Philippines, leaves, and unripe fruits of *M. oleifera* are used in daily basis in their cuisine. In India, this moringa is cultivated mostly for its oil. It is a type of oil that is characterized by a long shelf life and a rather delicate taste. (Al et al. 1986; Pandey et al. 2011)

There are many ways of cultivation these trees. In plantations, they are often cut down to small sizes and therefore look more like shrubs. It is a very fast-growing plant and tolerates radical pruning. Another advantage is that the plantations do not have to be irrigated in any way. Rainwater is often sufficient for its needs. Due to its hardiness and unpretentiousness, as well as its rapid growth, it is widely used in agroforestry and monocultures (Melesse 2011; Chadza 2012).

The botanical description is almost identical to that of *M. stenopetala.* It is a tree growing up to 12 metres. The bark is light grey to whitish. The biggest difference between *M. stenopetala* and *M. oleifera* can be seen in the leaves, which are light green, trifoliate (Figure 3.). The upper side of the leaves is feathery, and the underside is glabrous and can be 30 to 60 centimetres long. Lateral leaves are elliptic and larger than terminal leaves (Pandey et al. 2011).

Flowers are bigger and less dense that those of *M. stenopetala* and has strong, honey scent and might be up to 2.5 centimetres in diameter. Petals of flowers are usually white or pink with small dots and yellow stripes at the flower base. Each flower has five yellow stamens and five staminodes. Fruit is drooping capsule with usually brown colour. Three-valved capsules usually has nine ribs and has 15 to 24 seeds inside. When the fruit is mature and dry,capsule splits into two to three parts. Seeds has brown colour and has three soft, papery, deciduous wings (Pandey et al. 2011; Sagona et al. 2020).

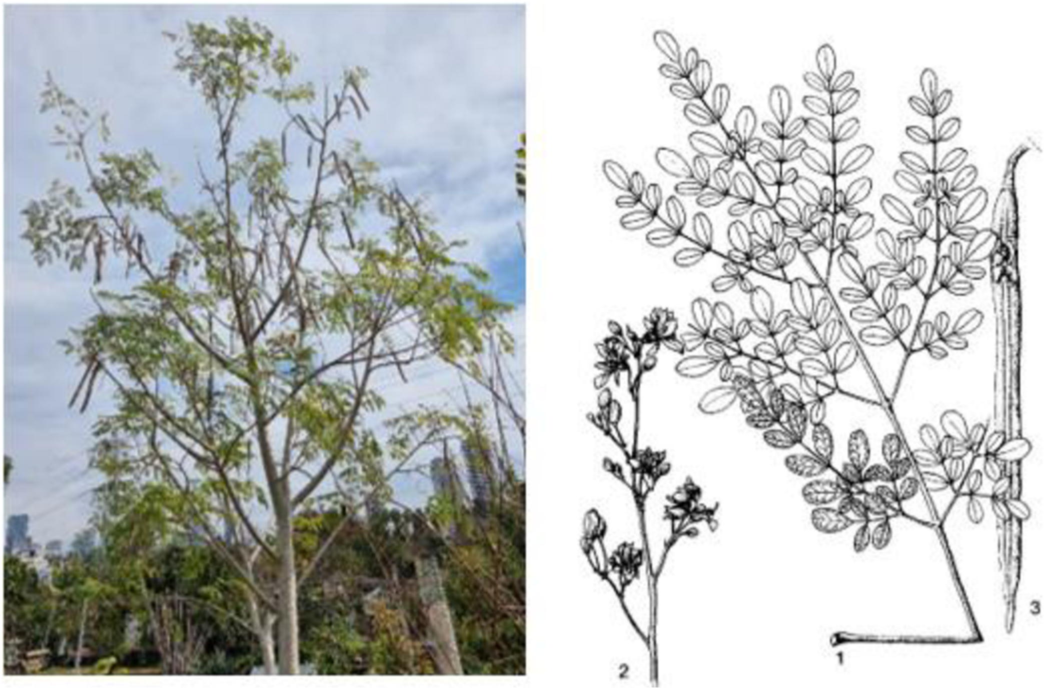

Figure 3. On the left side of the figure-*Moringa oleifera* (own photo, 2023 Israel) **and the line drawing of *M. oleifera* 1. leaf, 2. inflorescence, 3. fruit** (Polprasid 1996)

4.2.4. Chemical composition of *Moringa* spp.

Moringa spp. is characterized by its high content of various substances that are important for human health. Moringa leaves perform well in various nutritional tests, and it has been shown that cooked leaves are an excellent source of vitamin A and conversely, raw leaves are rich in vitamin C. They are also one of the best plant sources of minerals and B vitamins. It has also been shown to contain high amounts of calcium, which is not very common for plants. The iron content of the leaves is high enough to prevent anaemia in these regions, and it also contains low level of phosphorus. From the point of view of human nutrition, therefore, this is a rare combination of nutritional properties. However, the content of minerals, vitamins and other substances depends on many factors. The quantity is influenced by the season, the age of the leaves, the cooking process, and many others (Price 1985; Fuglie L. 2001; Melesse 2011).

For example, *M. oleifera* leaves, fresh or dried, contain a much higher gram-to-gram ratio of individual vitamins and minerals than other representatives of the plant kingdom (Figure 4.). The amount of vitamin C is up to 7 times higher than in oranges, the leaves contain up to 10 times more vitamin A than in carrots and the calcium content is up to 17 times higher than in milk. The protein content of the *M. oleifera* leaves is 9 times higher than that of regular yoghurt, and the iron content is 25 times higher than that of spinach leaves. Level of potassium is 15 times higher than in bananas (Fuglie L. 2001; Jed 2005; Longvah et al. 2017).

Content	Moringa leaves	Vegetables/ fruits	Amount of different compounds	References
Protein	6.7 g	Pea	5 g	Yadava (1996)
Calcium	185 mg	Spinach	99 mg	Teixeira *et al.* (2014)
Potassium	259 mg	Banana	88 mg	Fuglie (1999)
Magnesium	24.0 mg	Fig	17 mg	Fuglie (1999)
Vitamin A	6.8 mg	Carrot	1.8 mg	Chukwuebuka (2015)
Vitamin B_6	1.12mg	Kale	0.27 mg	Fuglie (1999)
Vitamin C	8.7 mg	Lemon	5.4 mg	Singh *et al.* (2001)
Iron (dry base)	19 mg	Spinach	35.8 mg	Joshi and Mehta (2010)
Fiber	0.90 g	Apple	2.4 g	Thurber and Fahey (2009)
Carbohydrates	12.5 g	Potato	16.8 g	Thurber and Fahey (2009)
Calorie	92.0	Avocado	160 cal	Fuglie (1999)
Fat	1.7 g	Papaya	0.3 g	Price (2007)

Figure 4. Nutrient contents of fresh moringa leaves and vegetables and fruits (bioactive material per 100 g product). (Yaseen & Hájos 2020)

The chemical composition of the two species is slightly different. Many factors can influence the chemical composition and content of the collected material. Some of the most common factors affecting the chemical composition of each representative include altitude, age of the plant, soil pH and composition and many others. Differences due to these factors may also exist between representatives of the same species grown in different locations (Melesse 2011; Debebe & Eyobel 2017). The chemical composition is slightly different in the pods, twigs or leaves (Table 1.).

The content of the main elements is most often given as ratios, usually grams per kilogram (g/kg DM), or milligrams per kilogram DM (mg/kg DM). DM is the percentage of dry matter, once the moisture form leaves has been taken out (Melesse 2011; Debela & Tolera 2013).

Table 1. Minerals of *M. stenopetala* and *M. oleifera* (Debela & Tolera 2013)

Minerals	***M. stenopetala***		***M. oleifera***	
g/kg DM	Twigs	Pods	Twigs	Pods
Calcium (Ca)	2.3	18.8	6.5	17
Phosphorous (P)	4.6	4.9	8.1	4.8
Sodium (Na)	0.5	2.4	0.43	0.6
Potassium (K)	26.1	18.1	19.8	32.3
Magnesium (Mg)	1.3	3.3	3.0	3.3

The most consumed part of these plants are the leaves. Since sorghum (*Sorghum bicolor* L.) is an important part of Ethiopian cuisine and is widely consumed (Tadesse et al. 2020), it has been added to the Table 2. for better comparison of mineral content.

Table 2. Mineral content in *M. stenopetala* leaves as identified by Debela & Tolera 2013; Debebe & Eyobel 2017; Ebenezar Udofia et al. 2020 **and *M. oleifera* leaves** (Vasan et al. 2008; Debela & Tolera 2013; Debebe & Eyobel 2017; Ebenezar Udofia et al. 2020) **in comparison to *Sorghum bicolor*** (Meschy 2004)

Nutrients g/kg DM	***M. stenopetala* leaves**	***M. oleifera* leaves**	***Sorghum bicolor* seeds**
Calcium (Ca)	12.1	12.9	0.4
Phosphorous (P)	3.0	6.2	3.4
Sodium (Na)	0.6	0.2	0.1
Potassium (K)	30.7	18.8	4.4
Magnesium (Mg)	2.8	1.8	1.7

In addition to minerals, essential amino acids also have an important role in nutrition. Amino acids in the leaves of *M. stenopetala* and *M. oleifera* are described in table 3.

Table 3. Amino acid content of the leaves of *M. stenopetala* and *M. oleifera* (Debela & Tolera 2013)

Amino acid g/kg DM	*M. stenopetala*	*M. oleifera*
Arginine	13.1	15.4
Cysteine	3.9	3.5
Isoleucine	9.4	10.9
Leucine	18.6	21.4
Lysine	12.2	13.2
Methionine	3.6	4.2
Phenylalanine	13.7	16.4
Threonine	11.4	13.0
Valin	12.0	14.0

4.2.5. Use of *Moringa* spp.

Both *M. oleifera* and *M. stenopetala* are cultivated primarily for their multiple uses and for their beneficial effects on human health. They are well known as high protein and nutritional food with medicinal properties and demonstrated antimicrobial activities in the human body (Fuglie L. 2001; Mekonnen 2002). It is also used as animal feed and has many general and industrial uses. For its properties, it is also used as erosion control, pollution control and as a soil improvement crop. Nearly every part of this plant has benefits for humans and almost every part of this plant may be used for human consumption. Leaves, seed pods, roots, mature seeds and even flowers were used by local people since time immemorial. However, it is only in recent years that global attention has been paid to it, as humanity has begun to realise the important role of such a crop (Mekonnen 2002).

Recently, it has also received interest in temperate climate countries, where, for example, dried leaves in powder form are sold as dietary supplement. The most common dishes are the one with cooked moringa leaves, which resembles spinach in appearance. In Ethiopia, but also in other countries, *Moringa oleifera* and *Moringa stenopetala* leaves prepared in this way can be seen daily. It serves as one of the main ingredients that is inherent in the diet of the local people. Moringa leaves can be found as a side dish with meat, fish, but also in soups or dishes for children. The very young leaves are also used in raw form- most often as a vegetable in various salads or other cold dishes (Mekonnen 2002; Seifu 2014). Consumed part of moringa are also their pods, which are used as vegetable. Fresh pods are most often cooked and are part of soups, sauces, or cold dishes. In addition to boiled pods, they can also be pickled or preserved in cans. Pods are exported from Africa and India to the rest of the world (Melesse 2011).

The seeds found in the pods are most often roasted and eaten in the same way as nuts. These seeds can also be fried or added to dishes like peas. However, they are primarily used to produce a very high-quality oil. On the market it is known as "ben oil". Its properties are remarkably like olive oil. It turns rancid after a very long time and has very versatile use. From cooking oil to one for making soaps. The seeds are also used to purify water (Mekonnen 2002). It has been shown that the substances in moringa seeds are able to rid water of bacteria and other compounds that would prevent the use of water for human consumption (Price 1985; Melesse 2011). Moringa flowers can be harvested almost all year round and are used as a cold preventative or for common cold (Melesse 2011). Moringa roots and tubers are also very often consummated. Grated or otherwise prepared, it serves as a garnish to various dishes and resembles horseradish in appearance and colour. It is not recommended to consume the roots too often, as they contain, in addition to beneficial substances, compounds that are dangerous to humans. They contain, for example, alkaloid spirachin, a nerve-paralysing agent. Care must be taken in its preparation to peel properly, as the bark of the root or tuber contains a high number of alkaloids, some of which are toxic (Price 1985; Melesse 2011). The last, often used component of moringa is undoubtedly wood, which is of very high quality. It is very soft and easy to work. The bark of these trees is also used to make high-quality ropes (Price 1985; Melesse 2011).

4.3. Pests

Among the most important pests encountered on moringa trees are mainly the larvae of various insects, budworms, and pod flies. Individual pests can be categorised, for example, according to the part of the plant they attack and destroy. These include, for instance, root feeders, leaf feeders, flower feeders and more. It is also possible to divide pests into so-called generalists, who have a wide range of host plants, and specialists, who are focused only on a particular plant species, in this case moringa trees (Kotikal & Math 2016, Deng et al. 2016). Research is also underway to create a hybrid form between *M. oleifera* and *M. stenopetala,* that would combine the properties of these plants (Price 1985; Melesse 2011).

Since very little research has been conducted directly in Ethiopia on *Moringa* spp. diseases or pests and almost no results are available, data collected for moringa cultivated in India (centre of diversity and the one of the largest producers) are often presented. Since the plant species, climatic conditions and pests and diseases correspond very closely to those in Ethiopia, the conclusion contained in this part of this thesis are reasonably applicable. In applying them, however, it is necessary to bear this fact in mind and check whether there are any specificities in the case in question which might affect the applicability of these conclusions in Ethiopia. The results of this work are not able to include all the pests that may occur in *M. stenopetala* and *M. oleifera* cultivation in Ethiopia. Also, not all non-invasive control methods for these plants are included. Only serious diseases and pests were selected, and the most effective non-invasive control methods that are used in Ethiopian agriculture were chosen for this thesis.

4.3.1. *Noorda blitealis* Walker

The most severe pest encountered in moringa trees in Ethiopia is the moth *Noorda blitealis* Walker:

-order: Lepidoptera

-family: Crambidae (Zhang et al. 2021).

This pest specializes only on plants of the Moringaceae family. The common name for this pest is moringa moth or leaf caterpillar. This pest is native to areas of India where it is causing considerable damage on *M. oleifera* trees. With the development of agriculture in Africa and the implementation of *M. oleifera*, this pest was introduced to the African continent together with a non-native species of moringa (Yigezu 2021). This pest species has been reported from many African countries where *M. oleifera* was introduced. Such countries, in addition to Ethiopia, include Kenya, Namibia, Gambia, Niger, Madagascar, and many others (Halder & Rai 2014). It attacks both species of moringa cultivated in Ethiopia (Halder & Rai 2014). *M. oleifera* has also been shown to be less susceptible to this pest (Haldhar & Susjil 2018; Chandraka & Gupta 2020). The larvae of this moth feed on the leaves, flowers, and buds of the moringa trees (Figure 5.). Damaged buds die and fall off. Infestation by this pest can be widespread and cause crop failures every season (Chellamuthu 2017).

Figure 5. ***Noorda blitealis*, larvae (A); pupae (B); Adults, ventral side (C) and dorsal side (D)** (Bedane et al. 2013)

This pest usually manifests itself by severe damage to the young and tender leaves of the moringa, often representing the most utilised harvestable part. In the early stage of development of the moth, larvae feed on the pods, flowers and green, chlorophylating part of the leaves, causing serious damage to the affected plant. The young larvae or caterpillars build webs on the leaves, which they roll into a coil. The leaves lose their natural green appearance and the damaged sheets become more paper-like in structure. Above all, there are losing function due to their lack of adherence to the green pigment. The affected plant is more susceptible to other diseases, is unable to withstand adverse conditions and, especially for young and immature plants, infestation by this pest is often fatal (Bedane et al. 2013; Halder & Rai 2014).

The colour of the body is predominantly brown in several shades. The wingspan can vary from 1.5 to 2 centimetres. The front pair of scaly wings is marbled brown, the hind pair is whitish with brown edging. The body of the moth is approximately 1 centimetre long. Adult individuals, in the form of moths, hatch from brown pupae that are hidden in the soil around the affected plants. After mating, the adults lay their creamy white eggs on the bottom of the leaves. The eggs after 2 to 3 days hatch (Figure 6.) into moth larvae, which cause the most serious problems. It remains in the larval stage for about 14 days (Chellamuthu et al. 2017). The colour of individual larvae varies considerably from white, to cream to pinkish. The size of individuals also depends on their feeding capacity (Abdelrahim et al. 2013).

It takes 6-9 days adult moth to emerge after pupation. Their total life cycle usually takes 16-26 days to complete. *N. blitealis* appear usually twice a year, mostly after the rainy season, which runs from April to August (Mamo Bedane 2013; Chellamuthu et al. 2017; Sharjana & Mikunthan 2019; Chandraka & Gupta 2020).

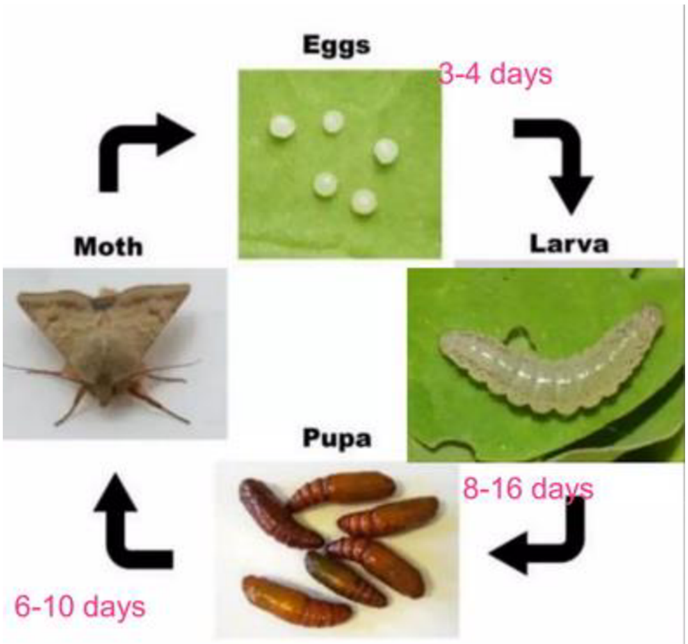

Figure 6. Life cycle of Noorda blitealis (Mahant 2016)

4.3.2. *Aphis gossypii* Glav. and *Aphis craccivora* Koach.

Group of so-called sap feeders or plant lice:

-order: Hemiptera

-family: Aphididae (Ebert & Cartwright 1997).

These two representatives of aphids are the most commonly found on moringa trees. These are generalists, and besides moringa, they also attack representatives of several other plants. *Aphis gossypii* (Figure 7.) can also be encountered with melon (so called melon and cotton aphids). *Aphis craccivora* (Figure 7.) can be found feeding on groundnuts and cowpea (Nevo & Coll 2001).

Young nymphs and adults feed by draining the plant sap and juices from young, tender plant parts. Most often from young, non-woody stems and leaves. Sucking out the sap causes yellowing of the leaves in the affected areas, and later drying and subsequent leaf drop (Ebert & Cartwright 1997). Their presence is often very easy to detect. The aphids are found in relatively dense groups on the stems or on the undersides of the leaves. And their dark body colouring makes them easy to spot. *Aphis gossypii* causing significant damage to cotton fields in Africa, also is widely distributed pest in the families Cucurbitaceae, Malvaceae and Rutaceae (Joshi et al. 2016; Ponnuswami 2016; Palada 2019).

Infestation by these pests is not fatal to the moringa plants. It can potentially threaten young plants, which may experience stunted growth but is not often that aphid attack is fatal. However, the greatest threat is the transmission of bacterial, fungal, viral and viroid diseases where these aphids act as vectors (Ebert & Cartwright 1997). Their main threat is therefore the possibility of transmitting diseases that can be fatal for moringa trees (Joshi et al. 2016; Palada 2019).

They occur very sporadically, and their occurrence has not been shown to depend on any factor. They are most common on moringa from January to March and spread very quickly (Joshi et al. 2016). This pest reproduces parthenogenetically in tropical and warmer areas (agents can reproduce without the male and female gametes being connected). The presence of these pests is often associated with the ants that feed on their sugary secretions, which the aphids excrete (Ebert & Cartwright 1997).

The appearance of an adult body size can reach up to 0.2 centimetres. Body colour can range from light green to almost black. Young nymphs are most often various shades of black, grey, or green. The eggs are yellow when laid, but soon turn black (Palada 2019; Kumar et al. 2020). The life cycle of these pests varies greatly depending on geographical location and average temperatures. Individuals in temperate zones have a completely different life cycle than those living in warm or tropical regions. In temperate climates, their life cycle is more complex. In addition to pathogenesis**,** i.e., females able to reproduce without males, in temperate climate zones males also fertilise eggs, which thus survive the winter season and can create new generations again in spring. In tropical or warm regions, we very rarely encounter eggs and winged males. Parthenogenesis takes place in these climates throughout the year. The females produce nymphs that mature to the adult stage within 7 to 10 days, which is capable of reproduction. The life span of females varies from 9 to 25 days. Single female can produce 25 to 125 young nymphs during their lifetime (Ebert & Cartwright 1997; Nevo & Coll 2001).

Figure 7. ***Aphis gossypii*****, adult with nymphs (left side of the figure "1.") and** ***Aphis craccivora*** **("2."), adult** (Tomazs 2022; Hinkley & Walker 2023)

4.3.3. *Indarbela quadrinotata* Walker and *Indarbela tetraonis* Moore

Serious damage to moringa trees and plantations is also caused by the moth *Indarbela quadrinotata* and *Indarbela tetraonis* (Mridha & Barakah 2017, Joshi et al. 2016)

-order: Lepidoptera

-family: Cossidae (Haldhar & Susjil 2018)

These are generalists that have not only moringa trees among their host plants. Their larvae cause damage by eating and destroying the bark of trees and other woody parts of the affected plant, causing irreversible damage and subsequent death of the afflicted parts. Many cases are reported from India and there might be a potential risk of introducing this pest into Africa (Raidas et al. 2016).

It has been observed that infestation of this pest occurs mainly in neglected plantations or in damaged moringa specimens (Ponnuswami 2016). Infestation by this pest is relatively easy to detect. Spots and paths are easy to spot on branches, trunk, and other parts of the plant, which are lined with a silky white net. In addition to the netting, excrement (frass) and chewed pieces of wood are also visible (Haldhar & Susjil 2018). As mentioned in the introduction to the subchapter, both pests cause the dying of the affected branches, resulting in a significant reduction in the yield and vitality of plants (Joshi et al. 2016).

In appearance, both pests are very similar at first sight. Therefore, a deeper knowledge is necessary for proper pest detection. The larvae, which are one of the life stages of this moth that are most damaging to plants, are very difficult to detect. Both larvae of these representatives are predominantly deep brown, burgundy, almost black in colour and range in size from 6 to 6.4 centimetres. Adults have light-coloured wings with a broad scarf of colour (Figure 8.). From shades of yellow, brown to grey. In both representatives, the first pair of wings has a distinctive brown marbling. In the case of the representative of *I. quadrinotata*, two brown spots are usually visible on the forewing pair. The lower pair of wings of both species is without distinct colouration, usually light brown. The body of both representatives is heavily hairy. The only distinguishing feature between these pest species is their size, with *I. tetraonis* being smaller in stature (Raidas et al. 2016). They also differ slightly in colour, with *I. tetraonis* having a lighter overall colour and more obvious marbling on the first pair of wings (Joshi et al. 2016).

The larvae are mostly active at night when they feed on the bark and later on the other woody parts of the plant. They can develop tunnels up to 20 centimetres deep, where they then enter the pupal stage after feeding. Silk nets inside the drilled paths serve as both shelter and protection. The larvae have a relatively long-life period. It usually lasts from 4 to 10 months. In the form of pupa, the pest is found from 3 to 4 weeks. The adult then hatches and soon lays its eggs into cracks and crevices in the bark of the host trees. The eggs hatch into larvae within 8 to 11 days. The entire life cycle of these pests lasts from 4 or 5 months to a year, depending on environmental conditions. This pest has so far been observed only in India and hance the information on life cycle length is applicable only to the Indian regions (Kumar et al. 2020).

Figure 8. Life stages of *Indarbela tetraonis* Moore, 1. Eggs, 2. Larva, 3. Adult (Venkata et al. 2022)

4.3.4. *Gitona distigma* Meigen

Another very common and quite dangerous pest is the drumstick pod fly.

-order: Diptera

-family: Drosophilidae (Sharjana & Mikunthan 2018)

Its original range is mainly southern India, where it still causes considerable damage. It is also currently a pest that is highly likely to start causing damage to *Moringa oleifera* plantations in Ethiopia, if imported there. However, there has been no evidence of such a case yet. This pest is a fly that is fully developed and specialized in damaging

M. oleifera. Currently, its occurrence is being associated with *Noorda blitealis* infestations, in which *N. blitealis* larvae consume the leaves and soft bark of the tree and the maggots (young developmental stage of *Gitona distigma*) consume the young and soft fruits (pods) of moringa (Joshi et al. 2016; Ponnuswami 2016; Sharjana & Mikunthan 2018).

Infestation by this pest is quite serious and can mean a loss of 75 to 100% of the crop (Sharjana & Mikunthan 2018).

As already mentioned, this pest specializes in destroying and consuming the pod and the inner part of the fruit (Figure 9.). In addition to the fruit envelope, moringa pot fly maggots destroy the immature, soft seeds. The affected fruit turn yellow from the tip and gradually dry out. The dry, maggot-damaged fruit may fall to the ground or remain on the tree, where they split from the pod tip over time. The presence of these larvae is often accompanied by to oozing of a rubbery substance from the affected fruit (Ponnuswami 2016).

The appearance of the adult fly is small; it can reach a size of 0.2 to 0.3 centimetres. The body colour is yellowish and is characterized by dark tripes all over the body. There is a black spot on each wing and the eyes are usually red. The female lays yellowish eggs in the groovers on the moringa fruit (Ponnuswami 2016). The incubation period of the eggs is usually about 3 days. The larvae then hatch and immediately burrow into the fruit and feed on the soft interior. They remain in this phase for about 16 days. Usually, with the damaged fruit, they fall to the ground, where they pupate and complete their life phase in the soil. The period in the pupa is about 7 days. Then the adult hatches and soon reproduce. The female can lie up to 200 eggs. The total life span of this insect is approximately 35 days in total (Mahesh S Math & Yallappa Kotikal 2015).

Figure 9. ***Gitona distigma*** **Meigen, 1. Maggot, 2. Poddamage, 3. Adult** (Suresh et al. 2022)

4.3.5. White grubs

In addition to the above-mentioned specific pests, so-called white grubs can be encountered on moringa trees (Suresh et al. 2022). These pests are the larvae of over 250 species from:

-order: Coleoptera

-family: Scarabaediae (Gashaw 2014)

Among the most common genus are beetles from genus *Cyclocephala* spp. where representatives include, for example so-called May June beetle, which is an annual grub, or *Phyllophaga* spp. (three-year grub) and *Popillia japonica*, the Japanese beetle (Gashaw 2014).

In Ethiopia, larvae of these pests cause significant damage to crop during the certain stage of their life cycle. They may live for several years in the soil where they feed on the underground parts of the plants. These pests are mostly associated with maize (*Zea mays*) cultivation in Ethiopia, where these larvae cause fatal crop damage (Gashaw 2014). However, these pests are generalists and do not specialize in eating specific plant species. Therefore, they can also be encountered on moringa trees (Heinrichs 1994).

Due to their life cycle, they can cause crop damage for several years. As adults, they can also damage the above-ground parts of the plans, where they cause damage on leaves. Since the larvae of this pest live in the ground, it is not easy to detect the species in time. Early signs of white grub infestation include the dieback of above-ground parts of the plant, which initially manifests in the gradual yellowing of leaves, withering of branches and more. (Heinrichs 1994; Gashaw 2014).

The appearance of the different larvae in different white grub species is almost identical. The differentiation of individual representatives and specific species requires considerable and deep knowledge in the field of entomology. Experts distinguish the representatives most often by markings on the bottom part of the larval bodies of individual larvae, which can vary from one representative to another. Their size can range from 0.6 to 2.5 centimetres. The larvae have usually 6 prominent legs and colour of the body is creamy white, often with shades of yellow or orange (Palada 2019). The head of larva is most often coloured dark brown, with black shades. As mentioned above, the larvae are most often found in soil, where they are most often found curled into the chape of the letter C (Gashaw 2014).

The life cycle and the way of life vary, depending on the species. For example, while the May-June beetle lays its eggs in the grasses around the host plant, the Japanese beetle most often lays its eggs directly on the host plant. Depending on many factors (e.g., temperature, rainfall, humidity, and food availability), the lifespan of a larva can differ considerably. May June beetles are native to North America regions, where they most often have a two-to three-year cycle can be observed. In Ethiopia, some representatives of the family Scarabaediae have one-year cycle. The adults lay white eggs in the grass, from which small larvae hatch after about 30 days. These larvae go through three stages. Each stage results in a larger, more robust, and more destructive individual that causes extensive damage. The larva hatches into an adult after about a year or more. Adults are active mainly at dusk and at night. Soon, after hatching, they mate and the whole life cycle repeats. The adults have a wide range of colours, depending on the species (Heinrichs 1994; Gashaw 2014; Joshi et al. 2016; Palada 2019).

Figure 10. White grubs, 1. Japanese beetle, 2. European chafer, 3. June bug (Cappaert, 2016)

4.4. Diseases

Thanks to the rapid development of moringa cultivation and climate change, diseases are becoming a major issue for the farmers. Diseases, as well as pests, cause irreversible and often very serious damage to the crop, limiting growth and product quality (Grace et al. 2020). According to the team of authors, about 12 diseases are known to affect *M. stenopetala* and *M. oleifera* worldwide, the vast predominance of which are fungal diseases (Grace et al. 2020). A major disadvantage (compare to pests) of the diseases is their relatively difficult detection at an early stage of their development. That is why plants are usually treated when the pathogen is already widespread. There are also cases where symptoms of disease infection are attributed to poor or inadequate nutrition. (El-Mohamedy et. al. 2014).

4.4.1. Fungal

Fungal diseases are the most common diseases in *M. stenopetala* and *M. oleifera*. There are several species of detrimental fungi and research in this area is still ongoing. Fungal diseases are the most serious problem in terms of crop destruction and yield reduction (Maninegalai et. al., 2011). In the chapters bellow, several of the most commonly occurring fungal pathogens of *M. stenopetala* and *M. oleifera* will be discussed.

4.4.1.1. Brown Leaf Spot

The most common fungal disease that can be regularly encountered with *M. stenopetala* and *M. oleifera* is Brown leaf spot disease. The pathogen is *Cercospora* spp. (Figure 11.), which is now one of the relatively extensively studied fungal disease in plants. Both moringa species are attacked by the pathogen *Cercospora moringicola* (Grace et al. 2020). Infestation with this fungus is characterised by the presence of brown spots on the leaves (Kirk & Wharton 2012). These brown spots are stromata from which grow conidiophores that produce yellow to brown conidia.

The affected leaves lose their natural green colour, turn yellow and soon fall off (Ponnuswami 2016). Pathogens are released from individual spores at temperatures between 20 and 30 ° C and at sufficiently high humidity. Temperature and humidity also play a crucial role in the development and subsequent expansion of the pathogen (Grace et al. 2020).

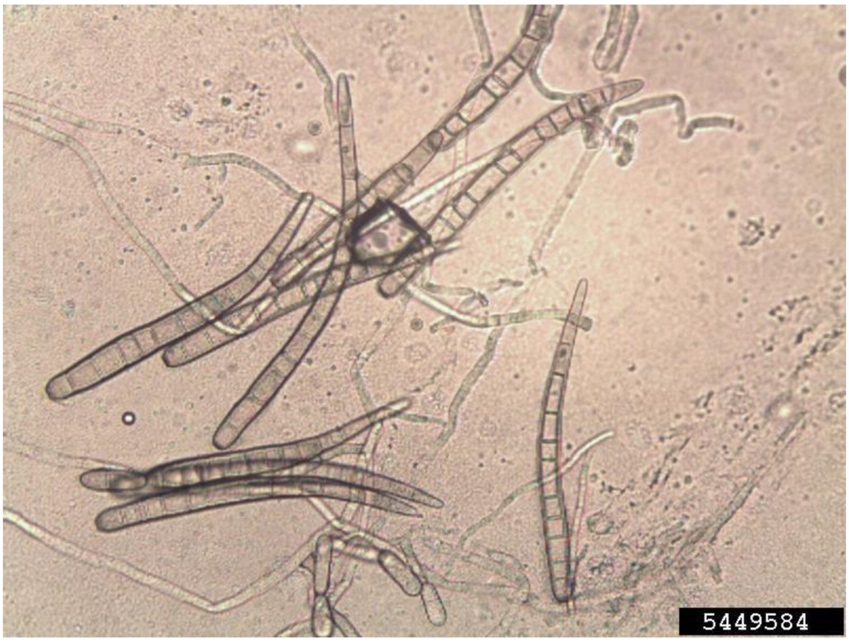

Figure 11. Conidia of *Cercospora* spp. causing Brown leaf spot disease (Brock 2011)

4.4.1.2. *Alternaria* Leaf Spot

A fungal disease that can be found quite often on *M. stenopetala* and *M. oleifera* trees is *Alternaria solani* Sorauer (Figure 12.), which attacks representatives of Solanaceae crops as well as Moringaceae. The symptoms of this disease are very similar to the previous ones, the Brown Leaf Spot. This disease is also characterised by brown spots on the leaves (Grace et al. 2020). The individual spots enlarge over time and spread over the entire leaf area (Matić et al. 2020). This prevents the leaf from functioning and the leaf dries out and wilts. In addition to the leaves, these necrotic spots can also appear on the branches (Ponnuswami 2016).

Primary infection occurs when there is infected plant debris in the vicinity of the potential host plant. With the help of fungus conidia present on the residue, the plant is infected, and infection develops. Secondary infection occurs through raindrops, wind, or insects. Conidia are released from the necrotic sites into the area. This disease occurs when there is high humidity and temperature (usually between 28°C and 30°C), while high soil moisture and rainfall are also important for the development of this pathogen (Ponnuswami 2016).

Figure 12. A single spore of *Alternaria solani* Sorauer causing *Alternaria* leaf spot disease (Bachi 2008)

4.4.1.3. *Diplodia* Root rot

Fungi of the genus *Diplodia* spp. are other representatives of the fungal kingdom that cause serious diseases of *M. stenopetala* and *M. oleifera*. The symptoms of this disease are not severe at first sight. Initially, the disease is primarily manifested by resin oozing out and running down the bark where it also dries out (Zeidan et al. 2016). Later, the leaves turn yellow, new parts of the plant grow slowly and gradually die. This disease exhausts the plant which is unable to produce new shoots. This reduces both fruit and leaf yield in *M. stenopetala* and *M. oleifera*. This disease can be very serious for young plants. Infestation by this fungus can be fatal to seedlings or, conversely, to old trees (Mridha &

Barakah 2017). It is transmitted by raindrops and wind from the male sex cells of the fungus, pycnidiosphores (Grace et al. 2020).

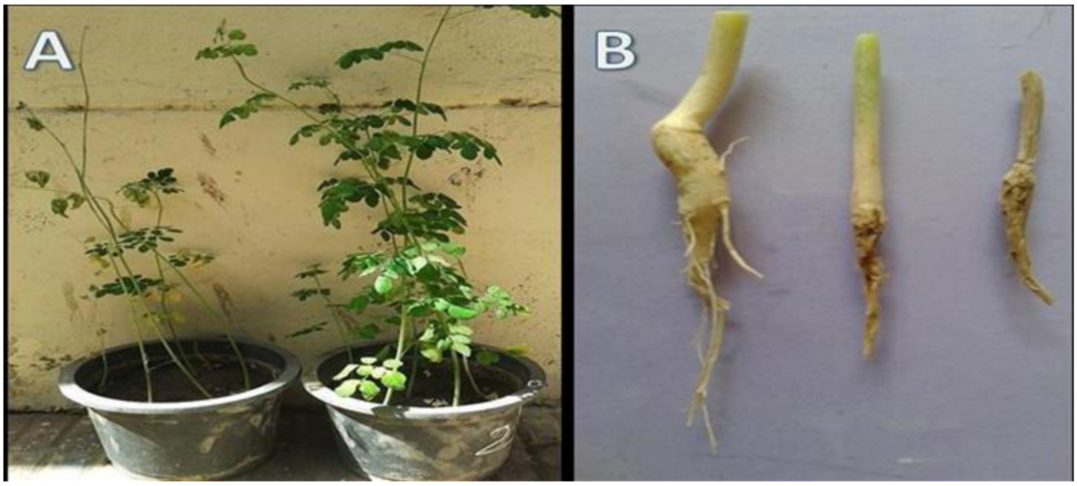

Figure 13. Root rot disease on *M. oleifera* (A) left pot shows infected plant, right pot control plant. (B) Left side shows control plant, on the right-side infected plants (Ziedan et al. 2016)

4.4.1.4. Damping off

Fungal diseases do not only affect mature plants. A very serious fungal disease is damping off, the pathogen of which is *Fusarium* spp. or *Rhizoctonia* spp. This disease causes extensive damage in nurseries where it destroys seedlings of young plants for plantation planting. Damping off can also have a bacterial agent. However, there are not known cases of bacterial damping off diseases on *Moringa* spp.

Fusarium spp. and *Rhizoctonia* spp. cause seedling death at a very early stage of development. Often the plant dies in embryo phase. Affected seeds have poor germination or do not germinate at all. Seedlings that emerge soon after germination wilt, wither, or rot. Dumping off is also influenced by abiotic factors including high humidity, waterlogging, low soil temperature before germination and many others (Lamichhane et al. 2017).

The pathogens can survive in the soil for many years without the host plant being present, and they also destroy the seeds themselves, which become necrotic when attacked (Lamichhane et al. 2017).

4.4.2. Viral and bacterial

Unlike the fungal diseases of *M. stenopetala* and *M. oleifera*, the viral and bacterial diseases of both moringa species are little studied. Viral and bacterial diseases can be transmitted by vectors, usually by aphids or whiteflies. Cankers may have two origins here as well. It can be fungal (in case of moringa caused by the pathogen *Fusarium pallidoroseum*) or bacterial (Mridha & Barakah 2017).

When moringa trees are attacked by a bacterial or viral disease, the affected trees are destroyed by farmers and attempts to save the plants are not currently practiced (Chuku et al. 2015; Mridha & Barakah 2017).

4.4.2.1. Mosaic viral disease of *Moringa oleifera*

As the name suggests, it is a disease of *M. oleifera.* Symptoms are always noticeable on the leaves. The disease symptoms may vary, but common signs include chlorotic leaf spots and leaf deformation. The leaves are usually curled and are significantly smaller in size than those of healthy representatives (Chuku et al. 2015).

4.4.2.2. Bacterial blight disease of *Moringa oleifera*

This disease, of a bacterial nature, has only been confirmed in *M. oleifera.* The symptoms of this disease are mainly present on the leaves. At first sight, the leaves appear damaged, an appearance reminiscent of fire damage. The leaves dry out, crumble, and gradually fall off (Chuku et al. 2015) .

4.5. Non-invasive plant protection methods used in *Moringa* spp.

Even though many diseases and pest can be now dealt with by chemical control, using insecticides, fungicides and many others, these options are being abandoned in the modern world. With the rapid development and implementation of advanced technologies, chemical methods are being dispensed. These chemical products may have a bad effect on the environment, they can affect the composition of soil organisms and the very health of humans who consume chemically treated plants (Montesinos 2003).

4.5.1. Prevention

M. stenopetala and *M. oleifera* are hardy trees that can grow and produce a yield in a fairy wide range of conditions. Nowadays, when these two moringa species are more frequently encountered, they may be exposed to conditions that are not very suitable for their cultivation. As a result, diseases and pests often occur, for example, due to improper cultivation methods or unsuitable conditions. Prevention is one of the methods that can reduce the occurrence of pests (Chadza 2012). Preventive methods include the selection and use of good quality, undamaged seeds or growing only apparently healthy plants and getting rid of damaged, deformed, or slow-growing and weak specimens (Mridha & Barakah 2017).

4.5.2. Human factors

Among one of the options for plant protection is the human factor. For example, through the mandatory quarantine that is legally imposed on imported plants, the occurrence of non-native pest species can be prevented and eliminated. In the case of *M. oleifera* and native species of *M. stenopetala*, most of the imported pests are mainly from the Indian subcontinent. Human factors may also include the quality standards of the imported plant (Rajinder et al. 2016).

To prevent contamination of agricultural material by pests, farmers are obliged to take only healthy and vigorous plants free from mechanical damage (Vincent et al. 2001). Many *M. oleifera* plants are imported into Ethiopia from India, where young plants are quarantined. But quarantine facilities are often in poor condition. The Government of India itself is addressing this problem and has set targets for the future to eliminate pests in their territory and on plants exported to foreign countries (Rajinder et al. 2016).

4.5.3. Intercropping

The intercropping system is the combined cultivation of crops at a certain time and place. Ideally, such a system should respect three basic rules:

- the preservation and sustainment of the natural environment
- the sustainable use of natural resources and
- the provision of a sustainable profit for the farmer (Sagona et al. 2020)

A well-functioning cropping system should result in higher yields with good use of natural resources, and stability of production even in adverse weather conditions. And of course, in a proper system, yields should be stable even when infestation by pests or diseases occurs (Grace et al. 2020).

Moringa is a very hardy woody plant that can tolerate hight temperatures, direct sunlight, and lack of water sources. In all cropping systems it is very important to select other plants that can tolerate conditions like moringa. Plants must be drought resistant and must tolerate high temperatures. Moringa provides shade for plants growing nearby (Figure 13.). Therefore, it is often planted as a tree that primarily protects other plants, farmers, and livestock from direct sunlight. They are often seen also as a fencing around smaller yields and around private properties, gardens. (Sagona et al. 2020).

There is only a small number of crop species with which it could compete on a common cropping system. Among those that cannot be grown together with moringa species are, for example, plants that require a lot of nitrogen in the soil. Other representatives are plants that compete with moringa trees for sufficient light. These include millet, eggplant, or sorghum (Chadza 2012; Ponnuswami 2016).

It is generally recommended to grow moringa with lower crop species and plants that can enrich the surrounding soil nitrogen and other substances. The most common plants grown with moringa are various types of vegetables, beans, soybeans, and other leguminous plants. Also, bitter gourd (*Momordica charantia*, Cucurbitaceae), sunflowers (*Helianthus annuus*, Asteraceae) maize (*Zea mayz,* Poaceae), or cassava (*Manihot esculenta*, Euphorbiaceae) and many more. Moringa trees are very non-competitive due to their root structure, which contains only large tuber roots growing near the plant and under the plant and a smaller number of lateral roots. Therefore, they do not compete with surrounding crops for water or nutrient (Price 1985; Ponnuswami 2016).

Figure 14. ***M. stenopetala*** **intercropped with maize, southern Ethiopia** (Kumssa et al. 2017)

4.5.4. Biological control and biopesticides

Biological control options include parasites or other predators that can fight the invasive fungus or pest (Kumar & Singh 2015). However, in addition to living organisms, this can also include breeding and development of new cultivars resistant to the pest (Ponnuswami 2016). Also, development of transgenic plants (GM) is one of the methods of biological control (Macek et al. 2008). Breeding of resistant cultivars, which is very time consuming is being carried out (Vincent et al. 2001).

In the breeding case, there is a possibility of breeding a cultivar-a cross between *M. stenopetala* and *M. oleifera*, which would be able to resist the *Noorda blitealis* pest in Ethiopia. According to scientific studies, *M. oleifera* is less susceptible and more resistant to this pest than *M. stenopetala*. Efforts are therefore currently being made to develop a cultivar capable of resisting this pest. However, the genomes of these two moringa species are not yet fully understood, so research must take place (Bartíková et al. 2020).

Elements of biological control include predators and parasites that can fight pests. In the case of Ethiopian *M. stenopetala* and *M. oleifera*, insect play a role here, for example, spider spices that can catch adult insect pests such as *Noorda blitealis* or

Indarbela quadrinotata and *I. tetraonis*, the spider living in Ethiopia, locally called "kelengelata", or spiders *Neoscona* sp., *Thomisus* spp., *Peucetia* spp., and *Agriope* spp. are important predator of these pests (Bedane et al. 2013; Chandraka & Gupta 2020). Other insect pests include the pentatomid bug (*Eocanthecona furcellata*), preying mantid or green lace. In Ethiopia, however, in addition to insects, there are also vertebrates that help in the fight against pests. Among the birds, except chickens (Sean Clark & Gage 1996), the blackbird, locally also called "awaleta", is a major predator of *M. stenopetala* and *M. oleifera* pests. Lizards locally called "telqyta" are also considered as important predators (Bedane et al. 2013).

Research in Pakistan in 2012 where eleven spotted beetle *(Coccinella undecimpuncata* Linnaeus) was introduced as potential predator of cotton mealybug, aphids, and other pests. This research has resulted in a significant reduction in the incidence of pests and recommendations for the introduction of these insects as a method of biological control (Hameed et al. 2013).

Biopesticides are substances used to protect plants based on natural compounds. Their main advantage is that they can be used in large quantities and can also be combined with the above-mentioned type of protection, so called biological protection (Vincent et al. 2001). Biopesticides also currently have many limitations that make it difficult to use them in large quantities. These include short shelf life, photosensitisation, or quick evaporation (Campos et al. 2016). The composition of each biopesticide varies depending on the target pest (Kumar & Singh 2015). However, the most common are products containing plant extract, bacteria, fungi, or nematodes (Tijjani et al. 2016). Examples of biopesticides are as follows: mycopesticides, bioherbicides, entomopathogenic bacteria (usually containing organism of *Bacillus thuringensis* Berl.), or entomopathogenic nematodes (Vincent et al. 2001).

Bacillus-based biopesticides are currently the most widely produced. The function of these biopesticides is based on the principle of insecticide effect of bacteria (Kumar & Singh 2015). Bacteria of the genus *Bacillus* spp. can form spores, which are structures inside cells that allow the bacteria to survive adverse conditions. The formulation of such spores is called sporulation, and this is what biopesticides are based on (Driks 2002).

During sporulation, bacteria of the genus *Bacillus* form crystalline inclusions containing proteins that have insecticidal effects. These are mainly proteins known as δ-endotoxins, or Cry proteins (Pérez-García et al. 2011).

Lipoproteins of the *Bacillus* genus also play a key role. These are antibiotics amphiphilic compounds (those that contain both hydrophobic and a hydrophilic part) and at the same time have the same molecular structure composed of a lipid tail linked to a short cyclic oligopeptide (Pérez-García et al. 2011). According to the amino acid sequence, lipopeptides are further divided into three groups (Ongena & Jacques 2008):

- Iturins, antifungal, limited antibacterial activity
- Fengycins, strong fungitoxic activity
- Surfactins, which have antibacterial activity but no fungitoxicity (Cui et al. 2012)

In commercial cultivation of *M. stenopetala* and *M. oleifera* it is therefore recommended to use these biopesticides, more precisely bioinsecticides to control pests from the families Lepidoptera, Diptera and Coleoptera. These bioinsecticides are very effective in controlling their larvae (Pérez-García et al. 2011).

For example, fungicide-based biopesticides based on fungal suspensions have shown positive effects against *Indarbela quadrinotata* pests. Larvae treated with a suspension of *Fusarium oxysporum* and *Beauveria bassiana* proved to be the most effective (Raidas et al. 2016).

Various essential oils and oils themselves are among the very promising substances that may replace chemical pesticides in the future (Campos et al. 2016). Such biopesticides include, for example, products based on neem-oil (also known as margosa oil). Neem oil is extracted from the seeds of the tree *Azadirachta indica* Juss., of the family Meliaceae (Baidoo et al. 2012). It is a plant native to the Indian peninsula, where it is used for its medicinal properties in folk medicine and as a substance to produce pharmaceutical drugs. However, its popularity is currently growing due to the development of biopesticides. The oil is extracted from the seeds and fruits and contains up to 100 bioactive compounds. However, the most important for plant protection purposes are the triterpenes, also known as limonoids. Of these substances, however, azadirachtin is the most important and is responsible for up to 90% of the pesticidal effects (Wondafrash et al. 2012; Campos et al. 2016).

Another plant material with proven effects against pests are extracts from tobacco plants (genus *Nicotiana*, family Solanaceae). Among the important bioactive substances is nicotine. More specifically the nicotine alkaloids, nornicotine and anabasine (Hanem 2012). Although they are highly insecticidal, their inclusion in common use is problematic. These alkaloids are synoptic poisons that are also dangerous to humans (Tijjani et al. 2016). Currently, the use of products with tobacco extract is being discouraged. It is used so far only in China and Africa, primarily to combat soft-bodied pests such as aphids (Majeed et al. 2016; Shahzad et al. 2017).

4.5.5. Mechanical, cultural, and physical control

These are some of the oldest yet functional methods of plant protection still used in the world today. In Africa, these are some of the methods that are still widely used. They are inexpensive methods requiring knowledge, which is often passed on for generations. The correct practices have been acquired by farmers over several years, even generations, through trial and error (Heinrichs 1994). In the case of cultivation of *M. stenopetala* and *M. oleifera* in Ethiopia, the most used methods are listed (Table 4.).

Table 4. Cultural, mechanical, and physical control methods (Heinrichs 1994)

Cultural	Mechanical	Physical
Plant density	Handpicking	Light trap
Mixed cropping	Digging out insects	Barriers
Weeding	Rolling the soil	
Trap crop		
Water management		

Water management is important in the prevention of fungal diseases. Both *M. stenopetala* and *M. oleifera* are very susceptible to rot and mould when waterlogged. Therefore, proper water management is essential for healthy plant growth (Němec et al. 2020).

In Ethiopia, *M. oleifera* trees are often grown in dense monocultures where the spread of pests and diseases is a much faster process than in agroforestry or intercropping. For this reason, plant density and mixed cropping is an important component in the non-invasive plant protection (Heinrichs 1994; Němec et al. 2020).

In the case of pests such as *Noorda blitealis, Indarbela quadrinotata, Indarbela tetraonis* or white grubs, mechanical control can be used. Hand picking can eliminate the number of larvae and adults on leaves or stems. On the other hand, rolling soil or digging out insects and collecting larvae can also reduce pest numbers (Gashaw 2014).

In the case of pests, barriers can also be used. Most often, these are fine nets that prevent the movement of insects. More sophisticated barriers include pheromone traps. In the case of *Noorda blitealis*, the sex pheromone is already known and genetically and biochemically described. It is therefore possible to use these traps in practice (Chandrakar & Gupta 2020; Zhang et al. 2021).

4.6. Non-invasive protection methods to specific pests and diseases

The Table 5. summarizes appropriate non-invasive plant protection methods of selected pests and diseases of *M. stenopetala* and *M. oleifera* in Ethiopia that are currently practised. The appropriate methods differ depending on the developmental stage of the pest. For winged insects, the most suitable management methods are cultural control, which may involve planting plants at lower densities or getting rid of weeds. Physical control methods that have been very successful in controlling insects include light traps (Heinrichs 1994).

Larvae are best controlled by hand-picking. White grubs, larvae or pupae in the soil, can be combated by soil work around the crop (Gashaw 2014). For fungal diseases, biopesticides are the most effective non-invasive method of control so far (Fenibo 2021).

Integrated pest management (IPM) can also be used to effectively protect these plants. This protection option combines the various non-invasive plant protection practices mentioned above with human knowledge of pests and diseases. Thanks to this, we can effectively prevent the multiplication of pests and their further spread without the use of chemical products. These methods are therefore completely safe, sustainable, and affordable (Bottrell 1979). However, appropriate strategies for exploitation are necessary and are not yet known for *Moringa* spp., their pests, and diseases.

Table 5. The final Table showing all the pests and diseases discussed and the most appropriate method of non-invasive control of Moringa spp.

Type of non-invasive plant protection method					
Pest	**Biological control**	**Biopesticides**	**Mechanical control**	**Cultural control**	**Physical control**
***Noorda blitealis* Walker** Adult	√		√	√	√
***Noorda blitealis* Walker** Larvae	√	√		√	
***Aphis gossypii* Glav**	√	√			
***Aphis craccivora* Koach**	√	√			√
***Indarbela quadrinotata* Walker** Adult	√		√		√
***Indarbela quadrinotata* Walker** Larvae	√	√	√		
***Indarbela tetraonis* Moore** Adult	√		√	√	√
***Indarbela tetraonis* Moore** Larvae	√	√			
***Gitona distigma* Meigen**	√			√	√
White grubs			√		
Diseases					
Brown Leaf spot		√		√	
***Alternaria* Leaf spot**		√		√	
***Diplodia* Root rot**		√		√	
Damping off		√		√	

5. Conclusions

With the growing popularity of moringa in the world, Ethiopia is witnessing the intensification of the cultivation of these plants. The indigenous species of moringa, id est *Moringa stenopetala* is slowly becoming a minority species, mainly due to its growth characteristics which are inferior compared to the non-indigenous *Moringa oleifera*. Although *M. stenopetala* still plays a very important cultural role in Ethiopia, it is now slowly but surely being replaced by *M. oleifera*. In the future, this may result in a reduction of global diversity.

The most serious pests of both *M. stenopetala* and *M. oleifera* is clearly *Noorda blitealis*. This pest causes extensive damage to leaves and fruits, and until not long ago, it has been very difficult to reduce its numbers. This pest has been properly studied to date and apart from the use of chemicals, hand-picking, nets, or predators (mostly spiders) are used in Ethiopia. However, in recent years, interesting results have been achieved in the field of plant protection, mainly due to the through genetic and biochemical description of the sex pheromones of this pest and their possible use in pheromone traps in both *M. stenopetala* and *M. oleifera* plantations.

Aphids do not pose a high risk to mature trees. However, a risk factor is the possible transmission of viral and bacterial diseases, for which no extensive research has yet been conducted in *Moringa* spp.

The following pests have not yet been confirmed in Ethiopia but pose a serious potential risk or danger: *Indarbela quadrinotata*, *Indarbela tetraonis*, and *Gitona distigma.* These pests cause extensive damage to Moringa plantations in India and due to many factors, there is a high risk of their possible introduction into African countries. Among the pests, fungal, bacterial, and viral diseases are currently described. Almost all fungal diseases are related to high humidity and especially waterlogging of the soil, to which moringa plants are highly susceptible.

In compiling these data, it was found that commercial cultivation of *Moringa* spp. in Ethiopia is still in early stages, especially on *M. oleifera* cultivation. No comprehensive material summarizing all pests or diseases in Ethiopia for moringa species is yet available.

Thus, this thesis is an attempt to summarize the pests and diseases of the most important moringa species, id est *M. stenopetala* and *M. oleifera* in Ethiopia territory and their non-invasive control methods. As discussed in the final table, methods of non-invasive plant protection vary for each representative depending on their developmental stage. However, more research is needed to optimize the efficacy and implementation of these methods.

No extensive research has yet been carried out on bacterial or fungal diseases. Therefore, the possibilities of non-invasive control methods for these pathogens are very limited and are not widely used in practice.

There is certainly much scope for future research in this area. To date, as mentioned, there is no comprehensive material describing all *M. stenopetala* and *M. oleifera* pests in Ethiopia and their appropriate non-invasive control methods. There is certainly even more scope in the area of diseases, where only a small number of fungal pathogens have been described so far. A study on the possible occurrence of bacterial and viral diseases in moringa trees is crucial for the future intensification of the cultivation of these plants in Ethiopia. In the area of non-invasive plant protection, further possibilities of using plant extracts or natural-based oils should be explored. It is also essential to implement IPM against these pests and to develop appropriate practices that can adequately protect these beneficial plants.

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