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Medicinal and aromatic plants of South-East Asia with potential for treatment of respiratory infections: a review of literature

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Medicinal and aromatic plants of South-East Asia with potential for treatment of respiratory infections: a review of literature" 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 18th April 2024

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Barbora Vera Karasová

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Abstract

Respiratory infections are posing a threat for people of all ages in countries from all over the world. They are especially dangerous for children under 5 years old and the elderly, as well as for people with weak immune system and people from low-income countries. Antibiotics are chosen as a conventional treatment for those infections, but their application is problematic for children and older people. They are also difficult to get for people living in rural areas due to their costliness, and a long distance to medical clinics. Another factor that should be taken into consideration is antimicrobial resistance, due to which antibiotics become less and less efficient. South-East Asia has one of the highest mortality rates due to respiratory infections. Laos is one of the poorest countries belonging to South-East Asia where 40% of the population lives there in rural areas and relies on traditional medicine. The country is covered by large forest that is hiding many unexplored plant species. The aim of this thesis was to analyse literature data and to collect new findings of medicinal and aromatic plants widespread in Laos including antibacterial activity of essential oils obtained from these plant species against respiratory pathogens. Total of 48 plant species belonging to the following families Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, Piperaceae, Rutaceae, and Zingiberaceae were found to be the most promising for future research. Out of those plant species, only 6 of them were studied for the antibacterial activity of their essential oils, therefore they are still considered as less known and unexplored. The tested plant species are *Actinodaphne pilosa* (Lauraceae), *Amomum dealbatum* (Zingiberaceae), *Amomum glabrum* (Zingiberaceae), *Clausena harmandiana* (Rutaceae), *Kaempferia champasakensis* (Zingiberaceae), and *Sphaeranthus indicus* (Asteraceae). Future research with special attention on antimicrobial activity of plant species presented in this thesis is needed to approve the potential of their essential oils in the treatment of respiratory infections.

Key words: antibacterial, antimicrobial, aromatic plants, inhalation, medicinal plants, Laos, respiratory diseases, South-East Asia

Abstrakt

Infekce dýchacích cest představují hrozbu pro jedince všech věkových kategorií pocházejících ze všech zemí světa. Obzvláště nebezpečné jsou pro děti a seniory, ale také pro lidi s oslabenou imunitou a obyvatele rozvojových zemí. Antibiotika jsou volena jako nejčastější způsob léčby těchto infekcí, ale jejich aplikace je problematická pro děti a jedince pokročilého věku. Také jsou obtížně k dostání pro lidi z rozvojových zemí, kvůli jejich vysoké ceně a dlouhé vzdálenosti do zdravotnických zařízení. Další aspekt, který by měl být brán v úvahu, je antimikrobiální rezistence, která zapříčiňuje, že jsou antibiotika čím dál tím méně účinná. Jihovýchodní Asie má jedny z nejvyšších čísel, co se týká úmrtnosti způsobené respiračními chorobami. Laos je jednou z nejchudších zemí Jihovýchodní Asie, kde 40% populace žije v odlehlých oblastech a spoléhá se na tradiční medicínu. Území je pokryto rozsáhlým lesem, který ukrývá mnoho neprobádaných rostlinných druhů. Cílem této práce bylo analyzovat dostupnou odbornou literaturu a sesbírat informace o nově objevených léčivých a aromatických rostlinách z Laosu a o jejich silicích testovaných pro antibakteriální aktivitu proti respiračním patogenům. Celkem byly nalezeny záznamy o 48 rostlinných druzích z čeledí Hvězdnicovitých, Hluchavkovitých, Vavřínovitých, Myrtovitých, Pepřovníkovitých, Routovitých a Zázvorovitých, které mají největší potenciál pro budoucí výzkum. Z těchto druhů, pouze 6 rostlinných silic bylo již testováno pro jejich antibakteriální aktivitu proti respiračním patogenům. Právě proto, že tyto rostlinné druhy jsou zatím málo známé a neprobádané. Testované rostlinné silice patřily druhům *Actinodaphne pilosa* (Hluchavkovité), *Amomum dealbatum* (Zázvorovité), *Amomum glabrum* (Zázvorovité), *Clausena harmandiana* (Routovité), *Kaempferia champasakensis* (Zázvorovité) a *Sphaeranthus indicus* (Hvězdnicovité). Je potřeba bližšího zkoumání rostlinných druhů zmíněných v této práci, se zaměřením na testování antibakteriální aktivity jejich rostlinných silic, aby se mohl potvrdit jejich potenciál k léčbě respiračních onemocnění.

Klíčová slova: antibakteriální, antimikrobiální, aromatické rostliny, inhalace, léčivé rostliny, Laos, respirační choroby, Jihovýchodní Asie

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List of the abbreviations used in the thesis

ARIs	Acute respiratory infections
DIZ	Diameter of inhibition zone
EOs	Essential oils
LRTIs	Lower respiratory tract infections
MIC	Minimum inhibitory concentration
RTIs	Respiratory tract infections
URTIs	Upper respiratory tract infections
WHO	World Health Organization

1. Introduction

Respiratory infections are posing a threat for people of all ages in countries from all over the world. They kill millions of people, annually. They are especially dangerous for children under 5 years, the elderly, and immune-compromised individuals (Jin et al. 2021; Safiri et al. 2023). In developing countries, the mortality rates due to respiratory infections are much higher because of limited access to medical clinics and pharmaceuticals (Ghimire et al. 2012). Globally, South-East Asia has the highest numbers of mortality rate due to respiratory infections (Feddema et al. 2021) and chronic respiratory diseases come as one of the main causes of death for the adults (Baptista et al. 2021). But even in a well- functioning healthcare system there are risks complicating the treatment of respiratory infections such as raising antimicrobial resistance (Teng 2014). That is why plant-derived products including essential oils come into a picture. They contain precious natural chemicals that are proven to possess antibacterial, antifungal, anti-inflammatory, antioxidant, and antiviral activities. Essential oils (EOs) are obtained from aromatic plants and due to their volatility, they have broad spectrum of applications, e.g. for food packaging as they produce natural preservatives and prolong the shelf life of a product, in the agriculture industry (allelopathic agents for weed control, natural herbicides and insecticides), and in the cosmetic industry (Bolouri et al. 2022).

They are of a great potential to be used for inhalation therapy to treat respiratory infections without causing side effects in the organism as they are delivered directly to the place of infection in the respiratory tract (Horváth & Ács 2015; Pasdaran 2016). In traditional medicine, many aromatic plant species are used, as they are easily accessible in rural areas, and the knowledge of them is spread among the healers. Therefore, developing countries and their heritage should be investigated to better understand traditionally used plants and their potential of killing respiratory pathogens without building up the antimicrobial resistance. Laos, a country in South-East Asia is often being overlooked by researchers, although it is hiding a great abundance of plant species, many of which could be the solution to the deadly infections of the respiratory system (Elkington et al. 2009).

2. Aims of the Thesis

The aim of this thesis was to analyse literature data and to collect new findings of medicinal and aromatic plants belonging to the families of Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, Piperaceae, Rutaceae, and Zingiberaceae, which are originated in South-East Asia. The identification of the essential oils-bearing plants distributed in Laos, that are the most prospective for treatment of respiratory infections, was the specific goal of this analysis. Summarization of scientific data such as traditional uses of selected plant species and their antimicrobial activity against respiratory pathogens were the main output of this work.

3. Methodology

A systematic literature review was performed by using professional scientific databases, such as PubMed, ScienceDirect, The Lancet, and Web of Knowledge, as well as by using relevant bibliographies, journals, and textbooks. The latest findings of medicinal and aromatic plants with distribution in South-East Asia and Laos were analysed. Studies evaluating antibacterial activity of essential oils against *Haemophilus influenzae*, *Staphylococcus aureus*, *Streptococcus pneumoniae*, and *Streptococcus pyogenes* and were searched for. A variation of following keywords was used: antibacterial, antimicrobial, aromatic plants, inhalation, medicinal plants, Laos, respiratory diseases, South-East Asia. The correct scientific name and synonyms of the selected plants were verified by using web-based database of World Flora Online, distribution of the selected plant species was checked on Plant of the World Online, run by Kew Science. Criteria for including plants into a comprehensive table were set accordingly: less than 50 records related to specific plant species on WOS database, distribution in Laos, and taxonomic classification into one of the following families Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, Piperaceae, Rutaceae, and Zingiberaceae.

4. Literature Review

4.1. Respiratory infections

Respiratory infections are the most common infections worldwide and the single most common infections seen in primary care. They are the most frequent indications for antibiotic prescribing. People that are at increased risk include those being either children under 5 years old, the elderly, underweight or obese, as well as people who smoke and live in large household (Hammond et al. 2021).

4.1.1. Epidemiology

Upper respiratory tract infections (URTIs)

The nasal cavity, pharynx, and larynx make up the upper respiratory tract (Gulati & Cullen 2008)

Upper respiratory tract infections (URTIs) include common cold, pharyngitis, tonsillitis and otitis media which create the vast majority of all respiratory infections. Common cold, pharyngitis, and sinusitis, are mostly caused by viral pathogens, and therefore do not acquire antibiotic treatment, if not complicated by bacterial invasion and infections in the lower respiratory tract (Jain et al. 2001). Infections affecting upper respiratory tract are usually self-limiting and do not cause fatal problems to middle aged population. They are characterised by symptoms such as cough, sore throat, nasal obstruction, and headache (Witek et al. 2015). Although, the mortality rates of URTIs are not that high, they cause major health problems for an affected individual. In a research based on the GBD 2019 study done by Jin et al. (2021) the estimated incident cases of URTIs reached 17.2 billion, globally and created 42.8% from all the cases of diseases and injuries. The age standardized DALY rate was calculated to be significantly higher in South-East Asia in comparison with other continents. And children mortality was mainly observed in low-income countries. It was confirmed that URTIs are the most dangerous type of illness for children under 5 years old and those older than 80 years old.

Lower respiratory tract infections (LRTIs)

LRTIs represent the vast majority of all respiratory infections-related deaths occurring in trachea, bronchi, bronchioles, and alveoli (Gulati & Cullen 2008). They are primarily of bacterial origin. Pneumonia, a severe infection in the lung parenchyma, is put into this group along with bronchitis and bronchiolitis. Pneumonia is characterized by a deepening cough, chest pain, fever, shortness of breath and sputum. Bronchitis and bronchiolitis symptoms include coryza and cough with fever and lead to the increase in numbers of mucus-producing cells in airways, as well as inflammation and loss of bronchial epithelium (Dasaraju & Liu 1996). Despite an overall decrease in mortality caused by lower respiratory tract infections, they still remain a global burden. In 2019 there were 489 million incident cases with 2.5 million of them leading to death (GBD 2019 LRI Collaborators 2022). They remained the world's most deadly communicable disease and 4^{th} leading cause of death, globally (Figure 1). For people living in low-income countries, the communicable diseases are even more dangerous. And, as shown in the Figure 2, lower respiratory infections are ranked at the second place of all causes of death (WHO 2020).

Feddema et al. (2021) collected information about LRTIs cases in fifteen countries of South-East Asia where the decrease of incidence appears inconsistent, showing data from 2000 till 2017. Interestingly, the lower income countries, such as Cambodia, Indonesia and Laos, managed to evidently decrease the mortality of children younger than 5 years old. In Laos the cases of death per 100,000 children went from 815.02 in 2000 to 300.48 in 2017. This might be thanks to Health Access and Quality Index improvement. But despite that progress being made, the mortality rate of children in low-income countries still exceeds the numbers of high-income countries where the occurrence of LRTIs-related causes of deaths in children is only 5 cases per 100,000 children. In Laotian adult, the lower respiratory tract infections represent the third leading cause of death in males and the fourth leading cause of death in females, as shown in the Figure 3. (WHO 2024). The risk factors contributing to LRTIs are the ambient particular matter, household air pollution, a lack of access to handwashing facilities, malnutrition (especially in children), and smoking (GBD 2019 LRI Collaborators 2022).

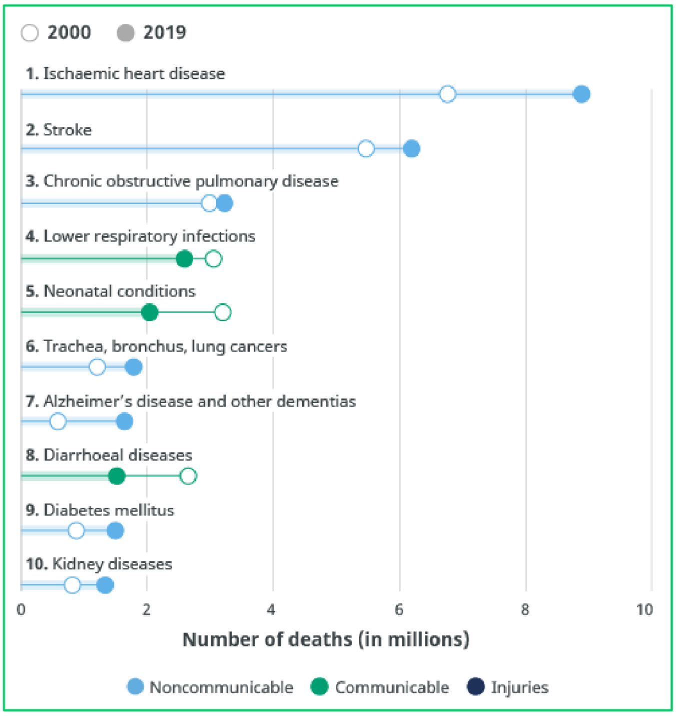

Figure 1 Leading causes of death globally: (WHO 2020)

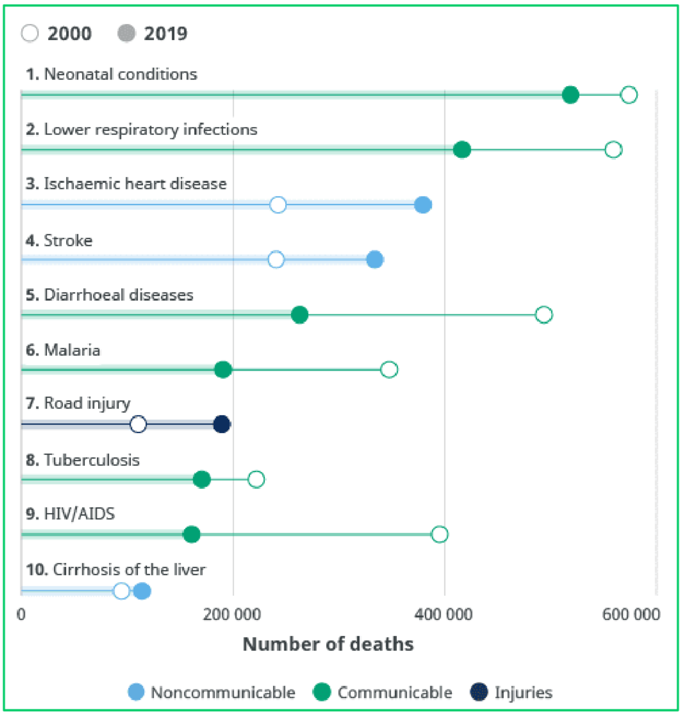

Figure 2 Leading causes of death in low-income countries: (WHO 2020)

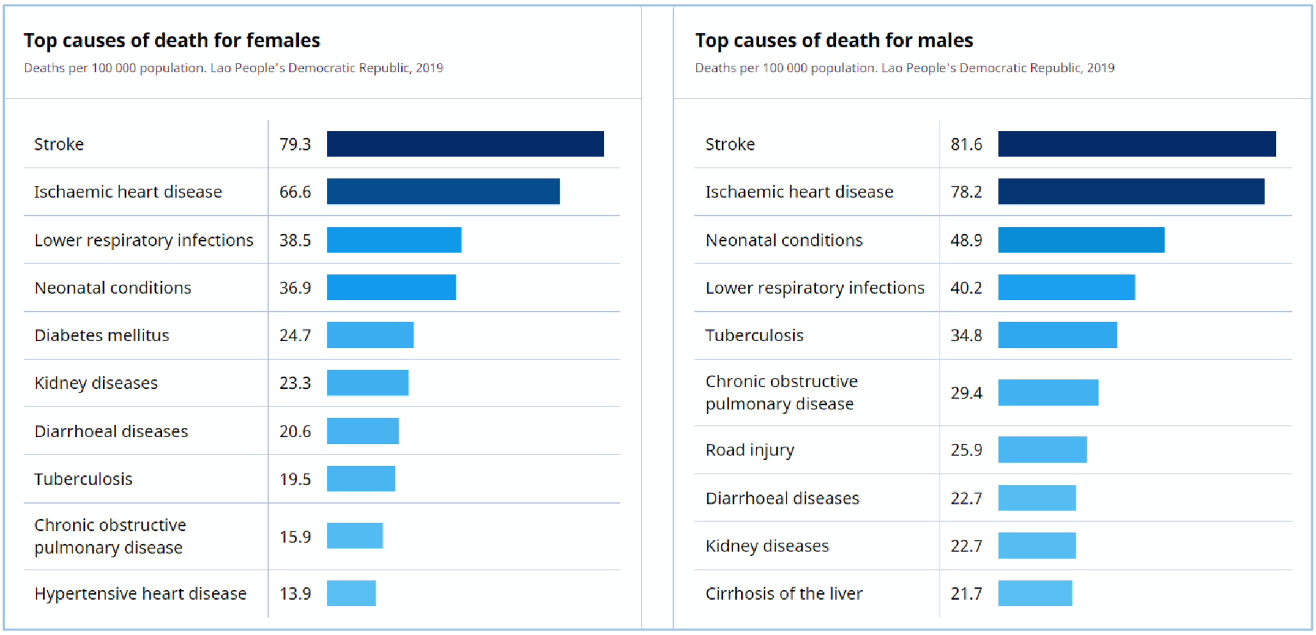

Figure 3 Leading causes of death in Laos: (WHO 2024)

Acute and chronic respiratory infections

Respiratory tract distortions can be also categorized by the urgency of their symptoms. Acute respiratory infections (ARIs) are those appearing suddenly and can be treated when acquired treatment is provided. However, they still are life threatening, especially for children under 5 years old, elderly and people with weak immune system (Simoes et al. 2006, Douglas & Cohen 2017; Shiratori et al. 2017). If the treatment is not working, acute infections can reoccur and become chronic. For example, bronchitis is known to be seen as chronic, although it primarily starts as acute (Cappelletty 1998).

In 2000 ARTIs caused deaths of almost 2 million children and 70% of all cases were reported in Africa and South-East Asia (Williams et al. 2002). In a recent study done by Caballero et al. (2019), it was stated that undeveloped countries are the ones having the highest numbers of child mortality, that is due to bad hygienic practices and poor parents' education. The percentage of all ARIs-related deaths is 4 times higher in undeveloped countries compared to those that have higher GDP growth (Oyejide 1988). Generally, 40% of global population sees a doctor due to symptoms of ARIs and 12-35% of them need to be hospitalized. The vast majority of ARI are those appearing in the upper respiratory tract (Jain et al. 2001).

Chronic respiratory diseases stay for a long period of time, usually for the rest of patients' life, they are responsible for serious health problems complicating daily activities. They include asthma, chronic obstructive pulmonary disease, occupational lung diseases, and pulmonary hypertension (WHO 2024). Bad air quality is the major contributor to chronic respiratory diseases. In cities, those contributors include domestic use of solid fuels, large industries, and traffic pollution. As well as individual behaviours and exposures, mainly indoor tobacco smoking. In rural areas the bad air quality is associated with increased outdoor use of solid fuels (Mohan et al. 2023).

4.1.2. Respiratory pathogens

Respiratory tract infections can be caused by bacteria, viruses, fungi or by their combinations (Debnath et al. 2022). In case of bacterial infections, *Haemophilus influenzae*, *Moraxella catarrhalis*, and *Streptococcus pneumoniae* are the most common pathogens attacking both upper and lower parts of the respiratory tract (Capalletty 1998).

The most dominant pathogens that are present in lower respiratory tract are Gram-negative bacteria, occurring in 96% of all cases. The most prevalent examples are *Pseudomonas aeruginosa* and *Klebsiella pneumoniae*. Gram-positive bacteria present in lower respiratory tract are *Staphylococcus aureus* followed by *Streptococcus* spp.. Yeasts such as *Candida* species can also be found (Bajpai et al. 2013).

For sinusitis, an infection of the lower respiratory tract, the most common bacterial agents are *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Moraxella catarrhalis*, *Staphylococcus aureus*, and *Streptococcus pyogenes* (Jain et al. 2001). Apart from upper mentioned risk factors, the complications of respiratory tract infections caused by bacteria come hand in hand with antibiotic resistance. The antibiotic resistance causes inability of treating respiratory infections and can lead to fatal problems. Another factor is already weakened organism that faces viral infections (Capalletty 1998).

For the upper respiratory tract stays as a fact constant exposure to microorganisms coming from the air. Many of those microorganisms are not dangerous, and even vital for the system. However, they are often accompanied by pathogenic species that colonize the upper respiratory tract and lead to serious infections. Pathogens found in the airways are most commonly Gram-negative bacteria, e.g. *Haemophilus influenzae*, *Streptococcus pneumoniae* and *Streptococcus pyogenes*. Strains of gram-positive bacteria *Staphylococcus aureus* only represent about 3% occurrence in URTIs but they can be responsible for a severe problems due to their strong resistance to ampicillins and methicillin (Gwaltney et al. 1992).

4.1.3. Conventional treatment

Antibiotics are considered as the most common conventional treatment for respiratory tract infections. Proper application of antibiotics can help to ease the symptoms and kill the bacteria pathogens. General population is getting prescribed antibiotics for RTIs several times annually which represents about 40% from all antibiotic prescriptions (Harris et al. 2016). Antibiotics are usually administrated either orally or intravenously, the sequential therapy is also advised. Antibiotics that are administrated orally include beta-lactam antibiotics (e.g. cefditoren), fluoroquinolones (e.g. levofloxacin), and macrolides (e.g. azithromycin). The intravenous treatment is selected for patients that have high heart rate, high respiratory rate, fever and poor tolerance to the oral rout. Antibiotics administrated intravenously are formulations of upper mentioned classes and acquire special devices and accessories, e.g. needles, infusion sets, syringes, and intravenous solutions (Cantón et al. 2022).

Antibiotics administrated by the intravenous route theoretically have 100% bioavailability due to short infusion that allows minimum drug elimination. However, there might be limitations because of the concentration-dependent drug toxicities and the vein exposure to high drug concentrations which can cause venous irritation and pain. For oral administration, the antibiotics are absorbed through systemic circulation and their bioavailability is significantly lower due to the action of gastric acid. Another factor that lowers the intestinal absorption is drug interaction, e.g. multivalent cations decrease the absorption of fluoroquinolones (Levison & Levison 2009).

The transport of oral antibiotics through the secretory pathway to the lungs involves multiple transporters being implicated in contributing to the drug's deposition in the liver, kidney, and intestinal tract and can potentially lead to the toxicity in those organs. Selective inhibitors are also present in the organism and reduce the absorption of the drug. Hence, inhalation therapy seems as a preferred mode of delivery as it can ensure direct deposition of the medication to the site of action and could reduce systemic toxicity (Ong et al. 2013).

4.1.4. Inhalation therapy

An alternative strategy that is being implemented in the antibiotic treatment of respiratory infections is the inhalation therapy that is working with aerosolized antibiotics and brings up many advantages. The drug dose given can be much smaller and the side effects are therefore being reduced. As the drug influences the respiratory tract directly and does not need to go all the way through the circulatory system, the onset action appears more rapidly, and the drug is not wasted via absorption in the parts of the body where it is not needed. Still, there remain problems, with over 250 inhaler devices being used today, for example dry-powder inhalers, nebulisers and pressurised metered dose inhalers with or without valve-holding chambers or spacers. The technic of using them properly is often difficult to learn for health practitioners and the patients (Usmani 2012).

Up until 1990 the aerosolized form of antibiotics constituted from compounds developed for parenteral uses which led to poor toleration by patients due to added preservatives. As a result, patients were facing hyperosmolarity causing induced bronchial irritation and bronchospasm (Dhani et al. 2016). Another side effects reported include cough, dyspnoea, haemoptysis, and wheezing. That was especially the case for tobramycin solution which led to even more serious health problems, such as voice alteration and tinnitus (Restrepo et al. 2012).

Since then, new studies using preservative-free and iso-osmolar formulations of antibiotics showed a decreased exacerbation rate and improvements in lung function. Still, the efficacy of inhalation medicine depends on many factors, including the particle size and molecular weight of a specific drug formulation, patients' anatomy with individual inhalation patterns, and mechanical ventilation-related factors, as well as device factors (Dhanani et al. 2016). The aerosolized antibiotics are not volatile, that is why the size of a specific particle, and its density determines the transportation to the affected area. The smaller the particles are, the easier it is to respire them, but in addition they can carry only little drug and have lower probability of bypassing the upper airways. The patients' ability to perform specific inhalation manoeuvres also affects the deposition of a particle. For example, children have smaller airways and higher inspiratory airflows than adults. A high inspiratory flow rate results in an increased deposition of drug in the upper airways, whereas a slow inhalation manoeuvre results in less a higher probability of aerosol particles bypassing the central large airways (Tiddens et al. 2014).

4.1.5. Antibiotics-related problems

Although, antibiotics are commonly prescribed and appear to be effective against bacteria causing respiratory tract infections, they pose significant problems due to its impact on individual's microbiota that affects the immunity system and the overall health. The disruption of a well-functioning microbiota leads to higher vulnerability to viral and bacterial infections and development of allergic diseases, as well as the inflammatory bowel diseases (Ubeda & Pamer 2012). The adverse events thar are being reported the most commonly include diarrhoea and rash but can lead to severe health conditions, e.g. anaphylaxis and sudden cardiac death. They also release harmful toxins and cell-wall components that can cause inflammation and tissue damage. In addition, a treatment of complications coming from inappropriate antibiotics use is expensive and might be resulting in fatal conditions (Harris et al. 2016). Moreover, their efficacy can be significantly reduced due to bacterial resistance which becomes a problem in last decades. Emergence of resistance during depends on the drug choice given to a patient. Antibiotics with a single ribosomal binding site are compromised by high frequency mutations that alter this site. For example, fluoroquinolones can select for mutants of Gram-negative bacteria and in a single step cause resistance to practically all classes of antimicrobial agents (Cižman et al. 2018).

The antimicrobial resistance itself is a dangerous problem affecting people worldwide and leading to many cases of deaths. Globally, in 2019 mortality associated with antimicrobial resistance reached 5 million cases and antimicrobial resistance in lower respiratory tract infections caused 1.5 million loses of lives. For example methicillin-resistant *S. aureus* was responsible for more than 100,000 cases of death (Antimicrobial Resistance Collaborators 2022). The predictions for mortality rates due to antimicrobial resistance seem to be the opposite of promising. By 2050 the antimicrobial resistance is calculated to be a cause of death for 10 million people, globally (O'Neill 2014).

The huge problem of conventional treatment is that antibiotics entering the pharmaceutical market are failing to meet the criteria for fighting the antimicrobial resistance. The impacts it has on morbidity, mortality, and economic losses is evident. Clinical testing and regulatory approval processes are slow and not much progress is being made. Even newly developed antibiotics are still not able to kill the most severe forms of resistant bacteria (Chinemerem Nwobodo et al. 2022).

Because of the antimicrobial resistance being an escalating issue, that adds to the numbers of mortality rate every year, effective alternative antimicrobial agents must be explored. One of the potential examples is the treatment using corticosteroids. This therapy appears to be effective in decreasing mortality rates but has its own adverse effects, such as hyperglycaemia (Feldman & Richards 2018). Numerous studies have been done to test the ability of essential oils coming from medicinal and aromatic plants and their antimicrobial compounds to prove that they can kill the multidrug-resistant bacteria. Essential oils seem to show exceptional activity against many dangerous bacteria, for example *Staphylococcus aureus* and *Mycobacterium tuberculosis* (Faleiro & Miguel 2018).

4.2. Phytomedicine

Current pharmaceuticals and nutraceuticals are from 50% of natural products and their derivatives. Compounds isolated from medicinal plants possess antioxidant, anti-inflammatory, and antimicrobial activities. They are able to inhibit the growth of bacteria, fungi, viruses, and protozoa. They are chemically complex and have a synergistic effect, therefore are of a significant clinical value in the treatment of resistant microbial strains. Compared with synthetic drugs, they have fewer adverse effects and enhanced bioavailability, solubility, and resorption rate. They also provide reduction of toxicity (Vaou et al. 2021).

4.2.1. Essential oils

Essential oils can be found in vascular plants, coming from about 50 families. They can be found in angiosperms (e.g., Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, Rutaceae, Zingiberaceae) or gymnosperms (e.g. Pinaceae). They are aromatic volatile substances present in the bark, flowers, fruits, leaves, roots, and the wood of stems. They are accumulated in specialized cells or glands, both on the outside of a plant (glandular brushes, papillae) and inside of a plant (secretory cells, intercellular spaces, secretory bags). They can be obtained either by distilling or cold pressing the secretory organs (Butnariu & Sarac 2018). The odour of aromatic plants is created for example by the action of phenylpropenes, e.g. anethole, estragole, eugenol, and chavicol. They can be detected as free volatiles and sequestered glycosides and are found in a range of economically important fresh fruits, such as apple, grape, and strawberry. Their notes are described as spicy anise- and clove-like (Atkinson 2018).

Aromatic and medicinal plants produce essential oils as the secondary metabolites which are usually a part of their defensive system. They protect the plant from herbivores and pests, on the other hand, they can attract pollinators and seed dispersers. They also serve a plant as info chemicals that are used via air-bone as a tool of communication with other plants (Kabera et al. 2014). Every plant has its unique mixture of EOs, that varies even within the same botanical species. The composition of EOs is influenced by many factors, e.g., climate, cultivation technique, the extraction method, chemotype, plant collection time, and soil composition (Guo et al. 2021).

Essential oils have been used for centuries for their bactericidal, virucidal, fungicidal, and insecticidal properties (Bakkali et al. 2008). For their approved activities against broad spectrum of pathogens they can serve as an alternative for treating human infections without the threat of antibacterial resistance that is happening as a result of antibiotic prescribing worldwide (O'Bryan et al. 2015; Taiwo & Adebayo 2017). Their antimicrobial activities have intensively been studied for decades and some promising results have been found. For instance, cinnamon, lemongrass, oregano, peppermint, and thyme essential oils are efficacious against the respiratory pathogen *S. aureus*. Lemongrass and thyme have been tested against *S. pyogenes* and have shown the highest (the diameter of inhibition zone 70 mm - 80 mm) antibacterial activity. Another EOs with antibacterial activity include lavender, oregano, peppermint, rosemary, tea tree, white fir, and ylang ylang, which all have shown high (DIZ 50 mm -80 mm) activity against *Mycobacterium smegmatis* (Abers et al. 2021). It was observed that Gram-positive bacteria are more sensitive compared to Gram-negative bacteria when exposed to EOs (Inouye et al. 2001; Abers et al. 2021; Piasecki et al. 2023). Moreover, it was investigated by Kalaiselvan et al. (2022) that essential oil vapours can effectively beat not only bacterial pathogens but also fungal spores and viruses.

4.2.2. Chemistry of EOs

Essential oils are natural, complex compounds that are volatile and characterized by a strong odour. They are and usually colourless liquids, lipid soluble and soluble in organic solvents with a lower density than water has. Their major composition is constituted of terpenes and terpenoids (Bakkali et al. 2008).

Terpenes are characterized by the combination of isoprene units, they have the primary structure of C_5H_8 and based on the number of isoprene units present, they can be classified into monoterpenes (2 isoprene units), sesquiterpenes (3 isoprene units), and diterpenes (4 isoprene units). The volatility increases with smaller numbers of isoprene units, terpenes with up to 3 units are highly volatile. Terpenoids are the oxygenated derivatives of terpenes (de Matos SP et al. 2019). In EOs monoterpenes and sesquiterpenes predominate. Additional compounds present in EOs are hydrocarbons, oxygenated derivatives (oxides, alcohols, aldehydes, ketones, acids), phenylpropane derivatives, and reaction products thereof (esters, ethers) (Butnariu & Sarac 2018).

In a much recent study, the specific component of EOs found in the Alpinia genus of Zingiberaceae family, called terpinen-4-ol, has been reported to have antibacterial and antibiofilm activity against respiratory pathogen *S. aureus*. Another chemical component that was also found to be effective against several bacteria, including S. aureus, appears to be β-caryophyllene. This component is additionally effective against *Escherichia coli*, *Klebsiella pneumonia*, and *Pseudomonas aeruginosa* (Van et al. 2021).

Examples of monoterpene hydrocarbons are namely α- and β-pinene, p-cymene, and terpinolene. Examples of alcohols are namely geraniol and menthol. Aldehydes include citronellal and ketones include carvone, menthone, piperitone, and pulegone. For phenylpropane derivatives, the members are anethole, cinnamaldehyde, and vanillin. Carvacrol and thymol, often incorrectly listed as alcohols, have shown to possess the highest antimicrobial activity among all those components (Knobloch et al. 1986).

Carvacrol and thymol are classified as phenols. They have unique properties and higher acidities due to their aromatic ring that is tightly coupled with the oxygen and have relatively loose bond between the oxygen and hydrogen (Sparkman et al 2011). High phenol content present in EOs was found to be significant for treating respiratory infections (Horváth & Ács 2015). In a complex study done by Inouye et al. (2001) multiple essential oils were tested against respiratory pathogens. Again, those containing either aldehyde or phenol as a major component showed the highest antibacterial activity, followed by essential oils containing terpene alcohols.

Phenol-rich EOs are especially those extracted from *Origanum vulgare, Satureja hortensis,* and *Thymus vulgaris* that are rich in terpenic phenols. Essential oil of *Origanum vulgare* is called oregano, EO of *Satureja hortensis* is called savoury, and EO of *Thymus vulgaris* is called red thyme. Other examples of phenol-rich EOs include clove bud and cinnamon leaves, both rich in phenylpropanoids (Guo et al. 2021).

4.2.3. Aromatic and medicinal plats

Plants with medicinal or aromatic properties that are used in pharmacy and perfumery are usually defined as medicinal and aromatic plants. They have antioxidant and antimicrobial activities that are used for treatment of many illnesses. Aromatic plants are those that contain essential oils in the bark, buds, leaves, seeds, twigs, flowers, fruits, and wood. As previously explained, essential oils possess several biological activities and are important for a protection of a plant. But they can also be extracted for uses on the human health. The antioxidant activities of aromatic and medicinal plants are influenced by growing conditions, as well as by methods of the extraction. Aromatic and medicinal plants that have been the most studied include families of Asteraceae, Lamiaceae, Lauraceae, Myrtaceae Piperaceae, Rutaceae, and Zingiberaceae (Samarth et al. 2017; D'Aquila et al. 2023).

Asteraceae is a family of flowering plants. Including the genus of *Artemisia*, *Baccharis, Calendula, Centaurea,* and *Echinacea*. Plants from the Asteraceae family contain essential oils and crude extracts which are traditionally used for the treatment of malaria and wound healing. They possess antimicrobial, anti-inflammatory, and antiparasitic activities. It has been proven that they are active against *Staphylococcus aureus* and *Escherichia coli* (Gou et al. 2023).

Plant species of **Lamiaceae** family may occur as herbs, herbaceous plants, shrubs, or trees. This family compromises more than 7000 species and about 240 genera. The genus *Plectranthus* is considered one of the richest in essential oils, other genera are for example *Ocimum*, *Mentha*, *Satureja*, and *Thymus*. The plant species include widely known herbs with aromatic properties, e.g., basil, lemon balm, oregano, rosemary, and sage. They are traditionally used for blood stimulation and circulation, digestion, and for strengthening the central nervous system. They are also used for food preservation. They are antiseptic, diuretic, and carminative. Moreover, they possess antioxidant, insecticidal, fungicidal, and bactericidal activities. The essential oil of *Ocimum gratissimum* have proven to inhibit the growth of *Pseudomonas aeruginosa*, *and Staphylococcus aureus* (Ramos da Silva et al. 2021).

The plant species of **Lauraceae** family are mainly shrubs and trees distributed across the tropics. Out of 55 genera, the most widely known are *Cinnamomum*, *Ocotea*, *Laurus*, *Litsea*, and *Persea*. Leaves of plant species belonging to this family are known for the high content of EOs which are rich in flavonoids and terpenes, e.g., *Cinnamomum camphora*, *Lindera erythrocarpa*, *Litsea japonica*, *Machilus japonica*, and *Neolitsea sericea.* They are active against many pathogens, such as *Bacillus cereus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella enterica*, and *Staphylococcus aureus* (Farias et al. 2023).

Myrtaceae is a family constituted of shrubs and trees that grows primary in wet tropical climate. Its members are used for wood and as spices. Some of the species have tasteful fruit that is being economically evaluated. Leaves are most commonly used as astringents. They are known to treat gastrointestinal disorders, infectious diseases and they help with brain bleeding. One of the largest genera of this family called *Myrcia* has leaves containing insulin, and therefore they are used for the treatment of diabetes. Flowers and stems of those plants also contain essential oils (Cascaes et al. 2015). One particular plant of this family called *Syzygium jambos* that contains high doses of tannin in its bark has been tested for antimicrobial activities and it has been proven that it is an effective agent against *Staphylococcus aureus*, and other bacteria in the *Staphylococcu*s genus (Djipa et al. 2000).

The plant species of **Rutaceae** family are flowering woody plants widespread in tropical and temperate regions. They are usually being referred to the citrus family. They comprise about 160 genera, the most economically valuable is *Citrus*, followed by *Fagara*, and *Zanthoxylum*. The plant species of this family include *Citrus aurantifolia* (lime), *Citrus limon* (lemon), *Citrus paradisi* (grapefruit), *Citrus sinensis* (orange), *Fagara leprieurii*, and *Fraxinus xanthoxyloides*. Their characteristic citrus smell is used in flavouring and perfumeries. Their fruit is edible, the leaves are known for antimicrobial activities and insecticidal properties. Essential oils of Rutaceae family contain ethanol compounds and can be extracted from leaves, roots, and stem barks (Tamokou et al. 2017). Other present bioactive compounds include coumarins, flavonoids, and terpenoids. Coumarins are valuable for their, analgesic, anticancer, anti-inflammation, antimicrobial, and antioxidant activities, and as a treatment for infectious diseases and gastrointestinal conditions. Moreover, 5-geranyloxy-7-methoxycoumarin, artanin, isopimpinellin, and phellopterin present in the roots of *Zanthoxylum nitidum* revealed activity against methicillin-resistant Staphylococcus aureus, with MIC value ranging from 8 to 64 μg/mL, also these components exhibit specific level of growth-inhibitory effect against *Escherichia coli* and *Pseudomonas aeruginosa* (Santos et al. 2023).

The plant species of **Piperaceae** family are herbaceous shrubs found to be growing in wet tropical areas. The family comprises of about 10 genera, and 2000 species, e.g., *Piper cubeba*, *Piper nigrum*, and *Piper longum* (Campos et al. 2007). Essential oils are mostly present in their fruits, seeds, leaves, branches, roots, and stems. They are commonly used in cooking as spices but can be beneficial for human health as well. For centuries, they are widely used for the treatment of urological and liver problems, for wound healing and skin conditions, and to relieve from fever and stomachache. They are anti-inflammatory, antioxidant and antimicrobial agents (Salehi et al 2019). Their antimicrobial activity is assigned to amides, alkaloids, essential oils, lignans, and phenylpropanoids. The major components of essential oils are ethanol, methanol, and petroleum ether which have been shown to inhibit the growth of *Bacillus cereus*, S*treptococcus agalactiae*, *Staphylococcus aureus*, and *Staphylococcus saprophyticus* strains with MIC values of 10, 6, 10, and 30 and μg/mL, respectively (Campos et al. 2007).

The plant species of **Zingiberaceae** family are flowering rhizomatous plants, widely distributed in the tropical and subtropical regions in humid lowland or higher altitudes, predominately in Asia. It comprises more than 50 genera, e.g., *Alpinia*, *Amomum*, *Curcuma*, *Globba*, *Hedychium*, *Kaempferia*, and *Zingiber,* with around 1 400 known species. Their rhizomes are used as spices in cooking and for making natural dyes. They are also rich in antioxidants and have anti-inflammatory properties. For example, the rhizomes of *Alpinia galanga*, *Boesenbergia rotunda*, *Curcuma longa*, and *Zingiber officinale* are typically used to treat diarrhoea, flatulence, and stomach-ache. Their leaves can be used for cooking as well, but only those of some species, such as *Curcuma longa*, *Elettariopsis slahmong*, and *Kaempferia galanga* are the key ingredients in spicy savoury dishes. The flowers are usually colourful with a nice smell, usually used for ornamental purposes (Rachkeeree et al. 2018). The essential oils of Zingiberaceae family have been evaluated for antimicrobial action on *Staphylococcus aureus* and *Escherichia coli*. (Oonmetta-aree et al. 2006). *Amomum* species are the second largest genera of Zingiberaceae family. They have an edible fruit with seeds that is traditionally used for digestive disorders, respiratory infections and in some parts of the world for the treatment of malaria. Anti-inflammatory effects of this genus have been confirmed and it has been recently observed that their EOs are able to reduce lung wet/dry weight ratios and protein concentrations (Zhao et al. 2022).

4.3. South-East Asia, Laos

South-East Asia is a tropical region that is known for its rich biodiversity. as it is an exclusive reservoir for plant species. South-East Asia has four biodiversity hotspots preserving the unique biota (Sodhi et al. 2004). Despite its smaller size compared to other tropical regions, South-East Asia composed around 50 000 recorded species of vascular plants, with an average of 364 new species being explored, annually. This makes South-East Asia the richest area in biodiversity when calculated on one square meter (Raven et al. 2020).

Laos is a small country belonging to South-East Asia region with 7.5 million habitants (World Bank 2022). The total area of Laos is 236.800 km^2. The climate is characterized as tropical monsoon. Laos shares boarders with Cambodia, China, Myanmar, Thailand, and Vietnam. The landlocked country is covered by large forest that makes up about 40% of all the area (Figure 4). As the forest is difficult to pass through, 80% of the population lives as farmers in rural areas. The forest preserves many medicinal plants that people tend to rely on before visiting a medical clinic far away from their houses. Homemade herbal medicine is less expensive and seems to be an efficient method of treatment (Elkington et al. 2009)

Laos is known for its ethnic diversity composed of Lao (53.2%), Khmou (11%), Hmong (9.2%), Phouthay (3.4%), Tai (3.1%), and other smaller ethnicities (CIA 2024). The Hmong ethnic group migrated to Laos in 19th century and holds a wealth of wisdom in the field of indigenous botany (Phengmala et al. 2023). Laos is being referred to as "the forgotten country", as it is being overshadowed by its larger neighbours, its land is landlocked, and due to political reasons, e.g., communist party, war than happened from 1953 to 1975, remains omitted from global perception, and therefore is in a state of economic tension (Jerndal & Rigg 1998).

Furthermore, Laos is an excellent candidate for studying ethnomedicine and ethnobotany as it has been overlooked by scientists, people there are educated about medicinal plants and are placed in a direct contact with them, and the forest is hiding many plant species that still to be explored (Elkington et al. 2009).

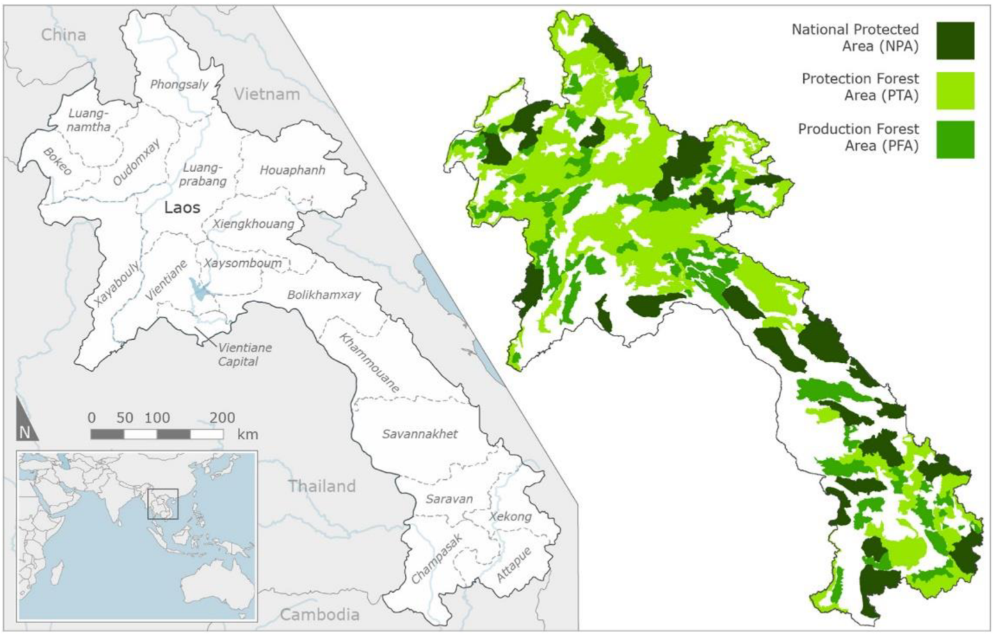

Figure 4 Map of forest area in Laos: (ScienceDirect 2019)

4.3.1. Traditional medicine

Traditional healers are usually members of a community which accepts them as someone who has the knowledge and practical skills to treat various illnesses by using natural materials, such as plants, mineral substances, and animals' remnants. Traditional healers are usually religious, in Laos mostly Buddhists, but they can also be practitioners of animism and others spiritual beings (Shankar et al. 2012).

In Laos, the traditional medicine is called "Ya Phurn Meuang Lao" and it has existed there for thousands of years. The government of Laos recognizes the importance of traditional medicine, and there is established the Traditional Medicine Research Centre under the Ministry of Public Health. The documented practices of Lao traditional medicine are archived as manuscripts from palm leaves and date back to 14th century (Elkington et al. 2009).

Because of upper mentioned factors, Lao inhabitants are familiar with using medicinal plants and herbs for healing. The herbal medicine is efficient and used for treating both chronic and acute diseases. Men are usually the heads of the families, and therefore it could be assumed that they are more educated about the indigenous knowledge of plants, as they have more time to study. However, it was stated that sex is a minor influencing factor, and women have at least the same amount of knowledge about medicinal and aromatic plants as men, because they need to be able to care for family members (Figure 5) Also, both lowland and mountainous districts, as well as urban and rural areas are skilled in the use of traditional herbal medicine. The herbal medicine is the most frequently used during childbirth, for the treatment of fever, gastrointestinal disorders, and malaria (Sydara et al. 2005).

The Hmong people historically consist of Chinese, Lao, Tai, and Vietnamese. They live in mountainous areas and are dependent on harvesting. They are even more segregated than the rest of Laotian people because of the Vietnam War, in which they were recruited by United States army against the communist party of Vietnam. As a result, they are afraid of the communist government in their own country. They are isolated from the central Laos and hiding in the large forest. For that reason they developed a self-sufficient lifestyle (Lor et al. 2017). They rely on herbal medicine and are skilled in identifying many medicinal and aromatic plant species. For example, they collect plant species of the Zingiberaceae family to treat digestive disorders, to increase male sexual potency, for neuromuscular problems (e.g. paralysis), and for skin problems. The genus *Amomum* is used for cough and hoarseness. In past, they were growers of opium. Among other, their traditional practices involve worshiping ancestors, animism, and cosmology (Dubost et al. 2019).

Phengmala et al. (2023) did an ethnobotany study of Hmong ethnic groups and revealed the most important plant species for edible and medicinal uses. Newly explored plant species are for example *Artemisia lactiflora* (Asteraceae), known as white mug wort. It is an edible plant that is used for treating many kinds of symptoms, e.g., eye symptoms, gastrointestinal system symptoms, musculoskeletal system symptoms, neurological symptoms, obstetrics gynaecology symptoms, and urinary system symptoms. Other commonly used plant species that are still not widely known are *Curcuma amarissima* (mango ginger) that is used as a treatment for gastritis, *Curcuma aurantiaca* (rainbow ginger) used for hypertension, and *Zingiber thorelii* (red ginger) used for gastritis and fever. All of them are from the Zingiberaceae family, and are used for nourishing the body.

Figure 5 Hmong woman picking herbs: (Laotian Times 2023)

4.3.2. Plants with potential for treating respiratory infections

Aromatic and medicinal plants that are containing EOs can be used in the treatment of respiratory infections via inhalation due to the volatility of the compounds contained. This appears to be practicable and have many advantages such as the affordability, ease of use, low toxicity, mild effects, rapid elimination, and significant efficacy (Liang et al. 2023).

Plant families growing in Laos that are the most recognized by its inhabitants and used as a source of food, as well as for medicinal purposes are Leguminosae and Zingiberaceae. Other plant families that the inhabitants are familiar with include Acanthaceae, Amaranthaceae, Apiaceae, Araceae, Asparagaceae, Compositae, Euphorbiaceae, Lauraceae, Moraceae, Myrsinaceae, Orchidaceae, Poaceae, Rubiaceae, Rutaceae, Solanaceae, Sterculiaceae, Verbenaceae, and Vitaceae (Dubost et al. 2019).

In this thesis, the aromatic and medicinal plants growing in Laos were analysed. The data collected from scientific articles and books were summarized in the Table 1. Through a literature review, 48 plant species belonging to 7 families, mentioned in the chapter 4.2.3., were identified. The scientific names of selected plant species (in alphabetical order), their synonyms, distribution, parts used, and their traditional uses are shown in the Table 1. The most abundant family that met all of the set criteria was a family of Zingiberaceae, compromising total of 34 plants, followed by 6 plant species of

Lauraceae family, 2 plant species from each of these families Asteracea, Lamiaceae, and Rutaceae. Only one species represented the families of Myrtaceae and Piperaceae. The *Amomum* genus of Zingiberaceae family was the most abundant representing the total of 26 plant species. Although, many of them have not been properly investigated, it can be expected that their properties are similar to well know relative species. The essential oils of *Amomum* sp. are most frequently extracted from seeds and have characteristic odour of cineol. They possess anti-inflammatory, alexipharmic, astringent, stimulant, and stomachic properties. The fruits are also rich in natural compounds, which exhibit antimicrobial activity, they are effective for example against S. aureus (Agnihotri & Wakode 2010).

Plant species containing EOs that have been already tested for their antibacterial activity against respiratory pathogens were put together. In total, 6 plant species have been selected, namely, *Actinodaphne pilosa*, *Amomum dealbatum*, *Amomum glabrum*, *Clausena harmandiana*, *Kaempferia champasakensis*, and *Sphaeranthus indicu*s. Descriptive pictures of these plant species are shown in Appendices 1-6.

The minimum inhibitory concentrations (MIC) of essential oils present in the selected plant species are shown in the Table 2. The laboratory method used for the evaluation of the antimicrobial activity of essential oils from those plants was in all cases broth microdilution. The microdilution method estimates the concentration of the tested antimicrobial agent in the broth medium using 96-well microtitration plate. The MIC is the lowest concentration of antimicrobial agent that completely inhibits the growth of the organism in microdilution wells (Balouri et al. 2016).

Table 1: Selected aromatic and medicinal plants from Laos

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Actinodaphne pilosa	Lauraceae	*Actinodaphne cochinchinensis, Jozoste cochinchinensis, Laurus pilosa, Machilus hainanensis, Machilus pilosa, Tetranthera pilosa*	leaves, wood	China, Laos, Vietnam	cough, furunculosis, rheumatism, swelling	wood is used for making hair and paper glues, insecticidal agent	Chung et al. 2020
Actinodaphne sesquipedalis	Lauraceae	none	buds, leaves, stems	Borneo, Cambodia, Indonesia, Malaysia, Myanmar, Thailand, Vietnam, Laos	stomachache	insecticidal agent	Woerdenbag et al. 1991; Omar et al. 2017; Tagane et al. 2020; Salleh & Khamis 2021
Alpinia chinensis	Zingiberaceae	*Languas chinensis, Monocystis abnormis*	flowers, leaves, rhizomes, roots, seeds	Brunei, China, Malaysia, Vietnam, Laos	arthritis, caning, cold, cough, respiratory inflammation, ringworm, stomachache	edible, aromatherapy	Hanh et al. 2014; Mei et al. 2020, Van et al. 2021
Amomum biphyllum	Zingiberaceae	*Elettariopsis biphylla*	not known	Laos, Thailand	not known	not known	Saenprom et al. 2018; Hlavatá et al. 2023
Amomum calcicola	Zingiberaceae	none	not known	Laos	not known	not known	Hlavatá et al. 2023

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Amomum dealbatum	Zingiberaceae	*Amomum siamense, Cardamomum dealbatum*	bark, leaves, rhizomes, seeds	India, Laos, Myanmar, Thailand, Vietnam	abscesses, diabetes, cough, joint pain, muscular rheumatism	cooking and eating ripe	Lamxay & Newman 2012; Leong-Skornickova et al. 2019; Pintatum & Laphookhieo 2022; Chelleng et al. 2023
Amomum glabrum	Zingiberaceae	none	leaves, rhizomes	China, Laos	antimicrobial activity against *S. aureus*	edible fruit and roots	Lamxay & Newman 2012; Chung et al. 2020; Cai et al. 2021; Thien 2021
Amomum chryseum	Zingiberaceae	none	not known	China, Laos	not known	not known	Lamxay & Newman 2012; Hlavatá et al. 2023
Amomum limianum	Zingiberaceae	*Elettariopsis limiana*	not known	Laos, Thailand	not known	not known	Hlavatá et al. 2023
Amomum odontocarpum	Zingiberaceae	none	not known	China, Laos, Vietnam,	not known	not known	Lamxay & Newman 2012; Hlavatá et al. 2023
Amomum petaloideum	Zingiberaceae	*Paramomum petaloideum*	not known	China, Laos	not known	not known	Lamxay & Newman 2012
Amomum plicatum	Zingiberaceae	none	not known	Laos	not known	not known	Lamxay & Newman 2012
Amomum prionocarpum	Zingiberaceae	none	not known	Laos	not known	not known	Lamxay & Newman 2012
Amomum repoeense	Zingiberaceae	none	not known	Cambodia, Laos, Thailand, Vietnam	not known	not known	Lamxay & Newman 2012; Ye et al. 2018

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Amomum sericeum	Zingiberaceae	*Amomum dealbatum var. sericeum, Cardamomum sericeum*	not known	Cambodia, China, Laos, Myanmar, Thailand, Vietnam	not known	not known	Hlavatá et al. 2023
Amomum subcapitatum	Zingiberaceae	none	not known	China, Laos, Thailand, Vietnam	not known	not known	Ye et al. 2018; Hlavatá et al. 2023
Amomum velutinum	Zingiberaceae	none	not known	China, Laos, Vietnam	not known	not known	Ye et al. 2018
Artemisia lactiflora	Asteraceae	*Artemisia septemlobata*	fruit, leaves, stems	Cambodia, China, Jawa, Laos, Taiwan, Thailand, Vietnam	eye symptoms, gastrointestinal system symptoms, musculoskeletal system symptoms, neurological symptoms, obstetrics gynaecology symptoms, and urinary system symptoms	edible	Phengmala et al. 2023

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	**Other**	
Clausena harmandiana	Rutaceae	*Clausena hirta, Clausena oliveri, Glycosmis cambodiana, Glycosmis harmandiana*	bark, flowers, fruit, leaves, roots	Cambodia, Jawa, Laos, Myanmar, Thailand	Alzheimer's disease bronchitis, headache, malaria, poisoning, stomachache, tuberculosis	edible, gardening	Maneerat et al. 2013; Boonyarat et al. 2022; Musa et al. 2022; Chambon et al. 2023
Curcuma amarissima	Zingiberaceae	none	bark, leaves, rhizomes, seeds	Bangladesh, China, India, Laos	dysentery, enteritis, gastritis, wounds	edible, flavouring, vermicide	Nimlamool et al. 2021; Phengmala et al. 2023
Curcuma aurantiaca	Zingiberaceae	*Curcuma wilcockii, Curcuma ecalcarata*	leaves, rhizomes	Jawa, Laos, India	gastritis, hypertension	edible, talismans	Phengmala et al. 2023
Curcuma clovisii	Zingiberaceae	*Stahlianthus thorelii*	rhizomes, roots	Cambodia, Laos, Thailand, Vietnam	bone and joint pain, cancer, digestion, haemorrhage, inflammation, menstruation, rheumatism, ulcers	not known	Nguyen et al. 2020; Yen & Li 2022

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Globba marantina	Zingiberaceae	*Ceratanthera amomoides, Colebrookia bulbifera, Globba angcorensis, Globba barthei, Globba heterobractea, Globba strobilifera, Globba timorensis, Globba zollingeri*	leaves, roots	Cambodia, China, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Vietnam	asthma, cold, cough, snake bite	flavouring	de Guzman & Siemonsma 1999; Roy et al. 2016
Kaempferia attapeuensis	Zingiberaceae	none	leaves, roots	Laos, Vietnam	gastrointestinal illness	edible, flavouring	Insisiengmay et al. 2019; Tuan et al. 2019
Kaempferia xiengkhouangensis	Zingiberaceae	none	leaves	Laos	cough, pigmentation, dermal stains	cosmetics	Saensouk et al. 2022
Kaempferia champasakensis	Zingiberaceae	none	fruit, leaves, rhizomes	Laos	allergy, cancer, diabetes, malaria, stomachache, urticaria, wound infections	flavouring	Picheansoonthon & Koonterm 2008; Hieu et al. 2023

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Litsea laeta	Lauraceae	*Litsea thomsonii, Malapoenna laeta, Malapoenna thomsonii, Tetranthera laeta, Tetranthera langifolia, Tetranthera thomsonii*	not known	Bhutan, India, Laos, Myanmar, Pakistan, Thailand, Vietnam	not known	not known	Tagane et al. 2020
Litsea rotundifolia	Lauraceae	*Actinodaphne chinensis, Actinodaphne rotundifolia, Iozoste chinensis, Iozoste rotundifolia*	not known	China, Laos, Taiwan, Vietnam	not known	not known	Tagane et al. 2020
Meistera calcarata	Zingiberaceae	*Amomum calcaratum*	not known	Laos	not known	ornamental plant	Lamxay & Newman 2012
Meistera elephantorum	Zingiberaceae	*Amomum elephantorum*	fruit	Cambodia, Laos, Thailand, Vietnam	not known	edible fruit	Lamxay & Newman 2012
Meistera chinensis	Zingiberaceae	*Amomum chinense*	fruit, seeds	Cambodia, Laos, Thailand, Vietnam	toothache	edible, flavouring	Lamxay & Newman 2012
Meistera celsa	Zingiberaceae	*Amomum celsum*	fruit, rhizomes	Laos, Vietnam	cancer	flavouring	Lamxay & Newman 2012; Giang et al. 2019

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Meistera koenigii	Zingiberaceae	*Amomum corynostachyum, Amomum koenigii, Cardamomum corynostachyum, Cardamomum koenigii, Meistera amomum, Zingiber corynostachyum*	fruit, rhizomes	Myanmar, Thailand, Laos, Vietnam	fever, headache, stomachache	ornamental plant	Lamxay & Newman 2012; Phan et al. 2020
Microtoena patchoulii	Lamiaceae	*Microtoena cymosa, Microtoena insuavis, Microtoena pauciflora, Plectranthus patchouli*	leaves	China, Laos, Myanmar, Nepal, Thailand, Vietnam	asthma, abdominal pain, cough	perfumery	Senpuku et al. 2007; Ito & Ito 2011
Neolitsea elaeocarpa	Lauraceae	none	not known	Laos, Vietnam	not known	feed for livestock, gardening	Tagane et al. 2020
Machilus gamblei	Lauraceae	*Persea bombycina, Persea gamblei, Persea suaveolens, Machilus bombycina, Machilus suaveolens*	fruit, wood	Bangladesh, China, Laos, Myanmar, Nepal, Thailand, Tibet, Vietnam	not known	edible, eliminating atmospheric carbon, gardening, wood	Upadhyay 2022
Piper politifolium	Piperaceae	none	not known	Laos, Vietnam	not known	not known	Tagane et al. 2020

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Pogostemon benghalensis	Lamiaceae	*Mentha integra, Origanum benghalense, Origanum indicum, Pogostemon frutescens, Pogostemon indicus, Pogostemon purpuricaulis*	bark, leaves, roots, shoots, stems	Bangladesh, Cambodia, China, India, Japan, Korea, Laos, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, Vietnam	colds, cough, headaches, snake bite, stomachache	patchouli oil-aromatherapy	Oyen & Dung 1999; Aryal et al. 2019; Tuyen et al. 2019
Sphaeranthus indicus	Asteraceae	*Oligolepis indicus, Sphaeranthus hirtus, Sphaeranthus mollis*	flower, leaves, roots, seeds	Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Sri Lanka, Thailand, Vietnam	cough, epilepsy, diabetes, fever, haemorrhoids, hepatopathy, leprosy, mental, illness, skin diseases	not known (weed)	Duraipandiyan et al. 2009; Galani et al. 2010
Syzygium tetragonum	Myrtaceae	*Eugenia subviridis, Eugenia tetragona, Syzygium nienkui*	leaves, twigs	Bhutan, China, India, Laos, Myanmar, Nepal, Thailand, Vietnam	allergy, diabetes, illness, skin diseases, haemorrhage, gastrointestinal, illness, inflammation, rheumatism	edible fruit	Han et al. 2012; Tagane et al. 2020

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Wurfbainia aromatica	Zingiberaceae	*Alpinia fasciculata, Amomum aromaticum, Amomum fasciculatum, Cardamomum aromaticum, Geocallis fasciculata, Renealmia fasciculata*	fruit, seeds	Bangladesh, Laos, Nepal,	abdominal pain, diarrhoea, malaria, respiratory infections, vomiting	edible fruit	Lamxay & Newman 2012; Dang et al. 2020
Wurfbainia glabrifolia	Zingiberaceae	*Amomum glabrifolium*	not known	Laos	not known	not known	Lamxay & Newman 2012
Wurfbainia longiligularis	Zingiberaceae	*Amomum longiligulare*	fruit, seeds	China, Laos, Thailand, Vietnam	gastrointestinal illness	edible fruit	Lamxay & Newman 2012; Yang et al. 2023
Wurfbainia microcarpa	Zingiberaceae	*Amomum microcarpum*	flowers, leaves, roots	China, Vietnam, Laos	cancer, digestive, disorders, gastrointestinal, illness, hepatopathy, malaria, postpartum, recovery	not known	Lamxay 2011; Lamxay & Newman 2012; Huong et al. 2015

Scientific name	Family	Synonyms	Parts used	Distribution	Traditional uses		References
					Medicinal	Other	
Zanthoxylum scandens	Rutaceae	*Fagara chinensis, Fagara cuspidate, Fagara cyrtorhachia, Fagara leiorhachia, Fagara scandens, Zanthoxylum chinense, Zanthoxylum cuspidatum, Zanthoxylum cyrtorhachium, Zanthoxylum laxifoliolatum, Zanthoxylum leiorhachium, Zanthoxylum liukiuense*	bark, leaves, roots, stems	Hong Kong, Laos, Vietnam	abdominal pain, HIV, rheumatism, toothache, traumatic injury	gardening	Cheng et al. 2008
Zingiber thorelii	Zingiberaceae	*Zingiber xishuangbannaense*	not known	Laos, Myanmar, Vietnam	fever, gastritis	edible	Phengmala et al. 2023

Table 2: EOs from Lao plant species tested against respiratory pathogens

Essential oils	Part used	MIC		Testing methods	References
		Staphylococcus aureus	***Pseudomonas aeruginosa***		
Actinodaphne pilosa	leaves	64 µg/mL	16 µg/mL	broth microdilution	Chung et al. 2020
Amomum dealbatum	rhizomes	1280 µg/mL	1280 µg/mL	broth microdilution	Pintatum & Laphookhieo 2022
Amomum glabrum	leaves, and rhizomes	5.67 µg/mL	no data	broth microdilution	Chung et al. 2020
Clausena harmandiana	twigs	ambiguous inhibition	no data	broth microdilution	Peerakam et al. 2022
Kaempferia champasakensis	rhizomes	8 µg/mL	no data	broth microdilution	Tran-Trung et al. 2023
Sphaeranthus indicus	flower	150 µg/mL	no data	broth microdilution	Duraipandiyan et al. 2009

5. Conclusions

Laos is a South-East Asian country with large area of forest and with the majority of population living in rural areas. The pharmaceuticals are difficult to come across, as medical clinics are far away from peoples' households and the classical treatment is expensive. Therefore, Laotians rely on herbal medicine that is an efficient alternative for treating many kinds of illnesses. The plant species growing there are still not widely explored, therefore they are of a great potential for future research (Elkington et al. 2009).

Respiratory infections are a huge problem in developing countries, especially for the children and the elderly. South-East Asia has one of the biggest scores of mortality rates related to respiratory tract infections and improvement there seems to be inconsistent. In Laos approximately 300 children out of 100,000 being born die from respiratory infections (Feddema et al. 2021), and in adults respiratory infections come as one of the major causes of death (WHO 2024).

This literature review presents total of 48 plant species that could potentially be used for the treatment of respiratory tract infections. The most promising plant species that have already been tested against respiratory pathogens, but still are not widely known are *Actinodaphne pilosa* (Lauraceae), *Amomum dealbatum* (Zingiberaceae), *Amomum glabrum* (Zingiberaceae), *Clausena harmandiana* (Rutaceae), *Kaempferia champasakensis* (Zingiberaceae), and *Sphaeranthus indicus* (Asteraceae).

In this thesis, literature data were analysed and new findings of medicinal and aromatic plants widespread in Laos were collected. Traditional uses of those plants and their antimicrobial activity against respiratory pathogens were summarized. Essential oils of only 6 plant species collected were tested for their antimicrobial activity against respiratory pathogens. Future research with focus on the antimicrobial activity of aromatic and medicinal plants presented in this thesis is needed to approve their potential in the treatment of respiratory infections.

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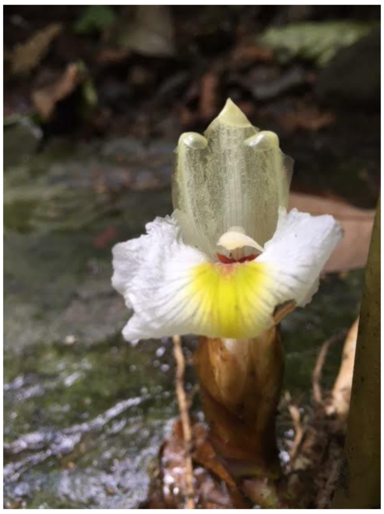
Appendices

List of the Appendices:

Appendices: Photos of the most promising plant species from Laos

Appendix 1: ***Actinodaphne pilosa*** (WordPress 2020)

Appendix 2: ***Amomum dealbatum*** (Useful Tropical Plant Database 2014)



Appendix 3: ***Amomum glabrum*** (ResearchGate 2019)


Appendix 4: ***Clausena harmandiana*** (Flickr 2013)


Appendix 5: ***Kaempferia champasakensis*** (ResearchGate 2008)


Appendix 6: ***Sphaeranthus indicus*** (India Biodiversity Portal 2015)