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Use of Plant Extracts to Extend the Shelf Life of Meat in Tropics and Subtropics in South America: The Case Study of Brazil

BACHELOR'S THESIS

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Author:

Lucie Štěpánková

Supervisor:

Ing. Iva Kučerová, Ph.D.

Declaration

I hereby declare that I have done this thesis entitled **"Use of Plant Extracts to Extend the Shelf Life of Meat in Tropics and Subtropics in South America: The Case Study of Brazil"** 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 date 10. 4. 2024

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Lucie Štěpánková

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Abstract

This bachelor thesis focused on plants that are used or can potentially be used for meat and food preservation in general. Due to their natural antimicrobial and antioxidant activity, plants are a suitable alternative to synthetic preservatives that may be harmful to health. Given meats susceptibility to spoilage, it is crucial to employ preservatives that maintain food quality and prevent spoilage and deterioration. The aim of this work was to identify plants with high antimicrobial and antioxidant activity in the context of the Brazilian flora. Both native and cultivated species were selected, with emphasis on specific plant parts with the best potential for preservation. In total, 22 plants and plant parts were selected that showed the best performance. Antioxidant activity was assessed using the DPPH method, leading to the selection of three plants with the most promising effect. These were *Plinia edulis* Vell. (leaf), *Syzygium aromaticum* L. (bud), and *Cinnamomum verum* J. Presl (bark) with DPPH IC50 values of 3.73 ± 0.12, 4.16 ± 0, and 4.34 ± 0.05 µg/ml. Subsequently, these species were described in more detail. The results of this work provide a foundation for further use of the selected plants in the field of food preservation and may serve as a basis for future research in this area.

Key words: preservation, herbs, spices, food spoilage, meat, meat products, shelf life

Abstrakt

Tato bakalářská práce se zaměřila na rostliny, které se používají nebo se mohou potencionálně použít ke konzervaci masa a potravin obecně. Vzhledem k jejich přirozené antimikrobiální a antioxidantní aktivitě jsou rostliny vhodnou alternativou k syntetickým konzervačním látkám, jež mohou být pro zdraví škodlivé. Vzhledem k náchylnosti masa ke kažení je zásadní používat konzervační látky, které udržují kvalitu potravin a zabraňují jejich kažení a znehodnocování. Cílem této práce bylo identifikovat rostliny s vysokou antimikrobiální a antioxidační aktivitou v kontextu brazilské flóry. Byly vybrány jak původní, tak pěstované druhy s důrazem na konkrétní části rostlin s nejlepším potenciálem pro konzervaci. Celkem bylo vybráno 22 rostlin a jejich částí, které vykazovaly nejlepší účinnost. Antioxidační aktivita byla hodnocena metodou DPPH, což vedlo k výběru tří rostlin s nejslibnějším účinkem. Jednalo se o rostliny *Plinia edulis* Vell. (list), *Syzygium aromaticum* L. (pupen), a *Cinnamomum verum* J. Presl (kůra) s hodnotami DPPH IC50 3.73 ± 0.12, 4.16 ± 0, a 4.34 ± 0.05 µg/ml. Následně byly tyto druhy detailněji popsány. Výsledky této práce poskytují podklady pro další využití vybraných rostlin v oblasti konzervace potravin a mohou sloužit jako podklad pro budoucí výzkum v této oblasti.

Klíčová slova: konzervace, byliny, koření, kažení potravin, maso, masné výrobky, trvanlivost.

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List of the abbreviations used in the thesis

PE - plant extracts

MS - meat spoilage

MIC - Minimum Inhibitory Concentration

DPPH - (2,2-difenyl-1-picrylhydrazyl)

ABTS - (2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonate))

1. Introduction

Nature has been and is a provider of medicinal plants that people can use for their benefit. This work focuses on already used and potentially useful plant extracts from Brazil that can help to preserve meat and meat products. Plants have antimicrobial and antioxidant activity, and their use can replace synthetic preservatives that are considered harmful to health (Proestos 2020).

The use of plant extracts is particularly appropriate in poor countries in the tropics and subtropics where people often do not have access to modern appliances such as refrigerators or freezers. Synthetic preservatives could be completely replaced by natural ones, which will not only help to reduce the impact on human health but also promote ecological sustainability (Awad et al. 2022).

2. Aims of the Thesis

The aim of the thesis was the investigation of available literature sources and electronic information databases to get a general overview of the possibilities of using various plant extracts to preserve meat in the tropics and subtropics in Brazil.

3. Methodology

This paper was written in the form of a literature review and summarized the information known to date on the use or potential use of plant extracts to extend the shelf life of meat in the tropics and subtropics of Brazil. The search primarily focused on plants with high antioxidant and antimicrobial properties. Information on the topic was collected from scientific internet databases such as ScienceDirect, ResearchGate, PubMed, Web of Science, and Web of Knowledge. The most frequently searched keywords were: "preservation", "herb and spices", "food spoilage", "meat and meat products". The entire paper was written in citation style with the title "Conservation biology". All sources were listed in the references.

Plants have been selected for their high antioxidant and antimicrobial activity, making them effective natural preservatives. All of these plants grow in Brazil, therefore, they consist of both native and cultivated species. Their comparison was conducted using the DPPH method, which evaluate their antioxidant effects and are summarized in a table for better overview. In addition, three representative plants with the highest antioxidant effects were identified after the assessment using the DPPH method described in detail.

4. Literature Review

4.1. Plant extracts

The plant extract (PE) or concentrate is obtained by extracting bioactive substances from the whole plant or its parts such as root, leaf, fruit, stem, seed, flower, and others. These substances contain in large quantities bioactive molecules that have antimicrobial and antioxidant effects and they are suitable as a preservative (Awad et al. 2022).

Bioactive substances, also known as compounds, are secondary metabolites present in plants (Juneja et al. 2017). While they are not crucial for the plant's survival, they contribute significantly to its defence mechanisms and interactions with the environment and other organisms (Kroymann 2011). These substances are distributed throughout different plant tissues and vary in their concentrations (Juneja et al. 2017).

Correct usage of PE, when applied at appropriate concentrations, can indeed serve as a safe and effective means to preserve meat while enhancing its quality (Olvera-Aguirre et al. 2023). An inappropriate dose can result in a change of taste in the meat, discoloration, poor action of the extract, and other negative effects. Concentrations between 200-1000 ppm are ideal for the proper effect of the extract (Velázquez et al. 2021).

The bioactive molecules found in plants are mainly polyphenols, followed by terpenoids, alkaloids, and organic sulfurs (Awad et al. 2022).

Polyphenols are particularly useful in the preservation of meat and meat products mainly due to their phenolic compounds. They inhibit the oxidation of meat (lipids and proteins), restrain the proliferation of pathogenic microorganisms, and prevent unwanted color change (Efenberger-Szmechtyk et al. 2021). Among phenolic compounds, flavonoids stand out as the most prevalent group, abundantly present in plants, particularly in vegetables and fruits (Olvera-Aguirre et al. 2023). Specifically, more than 9000 flavonoid substances are known today (Yuan et al. 2024).

4.1.1. Antioxidant activity

Numerous plants in the natural world have high antioxidant properties, predominantly among all higher plants (Kothari et al. 2012). The synthesis of antioxidants is caused by oxidative stress induced by environmental factors (Scartezzini & Speroni 2000).

In meat, these substances can suspend or completely stop oxidation processes (Shah et al. 2014). A high concentration of flavonoids and phenolics guarantees an antioxidant effect (Pandey et al. 2014).

The plant must be selected regarding its composition and the type of meat it will be used. The selection of the right part of the plant is also important. In a study, Kanatt et al. (2010) found that pomegranate peel extract has a high antioxidant effect, but the effect of seed extract is very low.

Plants with proven antioxidant activity include turmeric (Scartezzini & Speroni 2000), Chinese tea tree or basil (Aqil et al. 2006).

4.1.2. Antimicrobial activity

The purpose of substances with antimicrobial activity is to prevent spoilage and deterioration caused by microbes (Negi 2012). It is not only spoilage but also potential disease transmission.

Plants containing phenolic substances are usually very effective in fighting bacteria. These include, for example, garlic, ginger, rosemary, or clove (Skandamis et al. 2002).

4.2. Extraction of active substances from plants

It is possible to extract active substances from plants using a variety of solvents and methods. These methods may differ in efficiency, so it is necessary to choose the right one for the plant and the extracted part. It is equally important to choose the right solvent as well. Here the rule applies, polar solvents extract polar substances and non-polar solvents extract non-polar substances. Widely used solvents are for example: water, ethanol, chloroform, methanol, or some mixture of solvents (Kothari et al. 2012).

Water as a universal polar solvent extracts many substances and is mainly used because of its low cost (Das et al. 2010).

Many factors influence the quality of the PE. It depends on the used part of the plant, the type of solvent and its ratio, type of extraction, temperature, and lots of other things (Kothari et al. 2012). There are several techniques available for extracting active substances from plants, including distillation, fermentation, extraction, and enzymatic processes (Olvera-Aguirre et al. 2023).

4.2.1. Extraction methods

According to Kothari et al. (2012), the most used method is solvent extraction. Other widespread methods are pressing, sublimation according to the extraction principle, or distillation method (Zhang et al. 2018). The classical conventional methods include Soxhlet extraction, maceration, percolation, enfleurage, and others (Kothari et al. 2012). However, conventional methods usually have the problem with long extraction time of substances and thus the risk of thermal degradation for thermolabile substances (Chan et al. 2011).

In the following chapters, some frequently used or well-known extraction methods are described in detail.

4.2.2. Extraction process

The extraction of plant material is used to separate the active ingredients (Green 2004). It is important to take care of all the steps in the process to obtain a high-quality extract (Handa et al. 2008).

The first step in the extraction process is to collect plants of the appropriate quality. They can be used either fresh or dried (Abubakar & Haque 2020). After that, the plant material is reduced in size and extraction takes place. The material is extracted using the appropriate method and solvent. Once the extraction is complete, the extracted material is available for further use (Handa et al. 2008).

4.2.3. Soxhlet extraction

This type of extraction was introduced by Baron Von Soxhlet in the middle of the 19th century. It was the most widely used method until the 1980s when other extraction techniques appeared. The sample for extraction is placed in the porous thimble (Fig. 1). The solvent is heated in the flask. Once it reaches the boiling point, the vapor condenses and returns to the thimble. In this way, the sample is cycled until the extraction is complete (Luque de Castro & Priego-Capote 2010).

The big disadvantage is that the extraction takes a long time (6-48 h), due to cooled solvents, and uses a lot of it. On the other hand, it has been tested and used in comparisons with other methods (Mitra 2003).

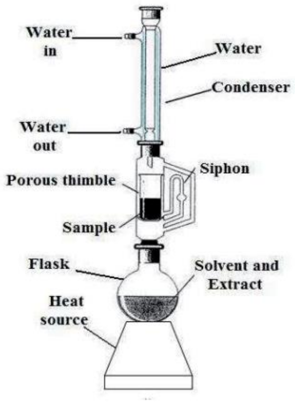

Figure 1. Soxhlet apparatus (Mitra 2003)

4.2.4. Microwave assisted extraction (MAE)

MAE is a simple and widely used method that converts the electromagnetic energy of microwaves to heat energy. The most used frequency is 2450 MHz with a power of 600 - 700 W (Jain et al. 2009). It combines 2 techniques, namely solvent and microwave extraction (Delazar et al. 2012). Microwave method used as an extraction was described in 1986 (Kapoore et al. 2018). MAE method is popular mainly due to its efficiency, low cost, and also due to its special heating mechanism (Chan et al. 2011). The extraction time ranges from a few minutes to half an hour, thus reducing the risk of degradation of thermolabile compounds (Chan et al. 2011). The solvent consumption is also very low (up to 40 ml) (Liu et al. 2008).

Since this is a successful extraction method, various modifications have been developed that are even more efficient than MAE alone. These include vacuum microwave-assisted extraction (VMAE), ultrasonic microwave-assisted extraction (UMAE) (Chan et al. 2011), pressurized microwave-assisted extraction (PMAE), and others (Delazar et al. 2012).

4.2.5. Maceration

Maceration is a simple extraction method especially suitable for thermolabile samples. The plant material, which is coarsely ground, is placed in a container. It is covered with solvent until the sample is completely covered. The container is sealed and left to infuse for at least three days. The effectiveness of this method depends on the quality of the plant material, the choice of solvent, and the correct maceration time (Abubakar & Haque 2020).

4.3. Meat

Meat is an essential aspect of our past, present, and future. Although there is speculation about whether it is good for humans or not, it is a very good source of nutrition. It contains many beneficial substances that are important for the proper development and functioning of the human body. These are mainly proteins, vitamins, unsaturated fatty acids, and mineral substances. Consumption of meat in reasonable quantities, especially in poor developing countries where people have bad access to food, is important. Nutrient deficiencies can cause various disorders and diseases for example anemia from iron deficiency (Baltic & Boskovic 2015).

The paradox is that eating meat can be good for us in terms of nutritional value, but it can also harm us. The most discussed in this regard is red meat and development of cancer (Baltic & Boskovic 2015).

There is no doubt that meat and meat products have played a large role in human evolution. Nowadays, we have a lot of information on why to eat or not to eat meat and everyone can decide for themselves (Baltic & Boskovic 2015).

4.3.1. Meat and spoilage

Awad et al. (2022) described: *"The presence of easily digestible, high-quality nutrients, moisture, and unsaturated fatty acids makes meat perfect food for spoilage by microbial growth, lipid peroxidation, and enzymatic autolysis."*

Improper processing and storage make the meat even more prone to spoilage. Antioxidants and antimicrobial substances are present in very small quantities making it unstable. It is therefore advisable to add these substances to meat (Bekhit et al. 2021).

Antimicrobials prevent the growth of pathogenic organisms and antioxidants inhibit oxidation (Awad et al. 2022).

Due to these spoilage factors, we can observe a negative change on the surface of the meat (color change, slime, ...) (Iulietto et al. 2015), as well as the change inside in its composition and structure (Dave & Ghaly 2011).

4.3.2. Types of meat spoilage

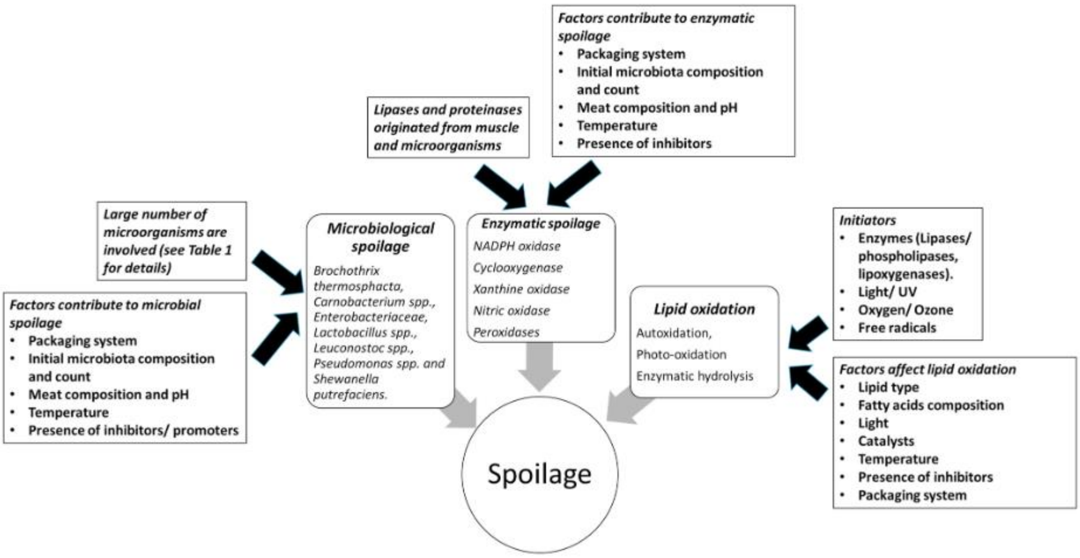

Figure 2. Factors responsible for spoilage (Bekhit et al. 2021)

Many factors are responsible for spoilage (Fig 2.). According to Dave and Ghaly (2011), there are three main types of meat spoilage (MS): microbial spoilage, lipid oxidation, and enzymatic autolysis.

4.3.2.1. Microbial spoilage

Spoilage by microbial growth is the most common of all those three types (Domínguez et al. 2019). Meat provides a good environment in which a wide range of microflora (bacteria, molds, yeasts) thrive (Jay et al. 2005). Spoilage, which is mainly caused by bacteria, is manifested by a change of color, odour, gases, slime consistency on the surface (Iulietto et al. 2015) and pH change (Dave & Ghaly 2011).

4.3.2.2. Lipid oxidation

After the microbial spoilage, lipid oxidation is the second most common cause of spoilage. Lipids are important in meat because they affect its flavor as well as its juiciness and tenderness. Unfortunately, they are very susceptible to degradation. Lipid oxidation is initiated by factors such as moisture, oxygen, heat, and light. We should therefore take care to control all intermediate steps from slaughter to final consumption (Domínguez et al. 2019).

Oxidation reactions lead to a reduction in the nutritional value of meat.

Oxidation will show up as a rancid smell, change of color, taste, or texture (Purriños et al. 2011). Last but not least, lipid oxidation produces toxic compounds that are pathological to humans and promote diseases (Broncano et al. 2009). The primary compounds produced by oxidation have no odor but are unstable and decompose rapidly. This leads to the formation of secondary compounds that cause unwanted odor and unpleasant taste of meat. Among the secondary compounds are alcohols, acids, ketones, esters, hydrocarbons, aldehydes, and others (Ross & Smith 2006). The aforementioned aldehydes in particular are present in many oxidized products and contribute to the unpleasant smell (JH 2016).

4.3.2.3. Enzymatic autolysis

The next and final cause of MS is enzymatic autolysis. It is a biochemical process that occurs naturally in the meat tissue after the animal is slaughtered (Dave & Ghaly 2011). Enzymes are still active after the death of the animal and break down proteins and other molecules. This results in a change in meat texture and flavor and subsequent meat deterioration. The action of these enzymes plays a major role in the storage of meat. The main enzymes are proteases, which break down the aforementioned proteins. They contribute to meat tenderness by breaking down muscle fibers and connective tissues (Bhat et al. 2018).

4.3.3. Meat and meat products preservatives

Preservatives are substances added to food products. They are used to maintain the quality or properties of food and slow down or completely prevent spoilage caused by microorganisms (Gonçalves et al. 2021).

The properties of preservatives should meet the requirements of being safe for health, edible, easily dissolvable in the food composition, demonstrate effectiveness across a broad pH spectrum, and have no negative impact on sensory properties (Awad et al. 2022).

Preservatives are divided into synthetic and natural. Syntetic ones are butylated hydroxyl toluene (BHT), tert-butyl hydroxyquinone (tBHQ), nitrates, nitrites, and others (Olvera-Aguirre et al. 2023). Natural ones are for example flavonoids, phenolics, essential oils (Awad et al. 2022).

Synthetic substances are mainly used in the meat industry. They are often associated with cancer because they are volatile at higher temperatures (Velázquez et al. 2021). Many substances with antimicrobial and antioxidant activity are found in nature and meet the quality and food safety conditions (Awad et al. 2022). Studies show that natural compounds polyphenols have a better antioxidant effect than synthetic ones (Olvera-Aguirre et al. 2023). Therefore, they could be used more widely or completely replace conventional chemical preservatives as they are preferable in almost every way (Awad et al. 2022). They not only combat spoilage effectively but also offer many positive health effects (Munekata et al. 2020).

4.3.3.1. Methods for assessing antimicrobial and antioxidant activity

Plants serve as excellent aids in meat preservation. To utilize specific plants, it is essential to determine their antimicrobial and antioxidant activity. Plants with high activity levels are suitable choices, as they contain bioactive compounds that effectively combat spoilage (Silveira et al. 2019). In the following chapters is a brief description of methods.

4.3.3.1.1 Methods for assessing antimicrobial activity

Antimicrobial activity can be measured in many ways. The most commonly used method is the Minimum Inhibitory Concentration (MIC) method (Silveira et al. 2019).

4.3.3.1.1.1 MIC method

It is a common technique to assess the antimicrobial activity of substances, including plant extracts. The MIC is the lowest possible concentration that can visibly inhibit the growth of microorganisms, usually within 24 hours. This means that the lower the MIC value, the greater the antimicrobial efficacy. MIC is most often given in units micrograms per millilitre (µg/ml) (Kowalska-Krochmal & Dudek-Wicher 2021).

Plant extracts are tested against specific bacterial strains. When plants are used in preservation, bacteria related to food spoilage are tested. These are the most common bacterial species: *Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Enterococcus faecalis*, and others (Silveira et al. 2019).

4.3.3.1.2 Methods for assessing antioxidant activity

Methods DPPH and ABTS are two simple and frequently used methods to assess the antioxidant activity of PE and other substances. These methods rely on the ability of the sample to scavenge free radicals. Their advantage is mainly cheapness (Rumpf et al. 2023).

4.3.3.1.2.1 DPPH method

The DPPH method is based on its ability to react with antioxidants. 2,2-diphenyl-1-picrylhydrazyl (DPPH) is a strong nitrogen radical with an absorption maximum at 515 nm (Dudonné et al. 2009). DPPH is mixed with the extract or substance to be tested and then the colour change of the solution is monitored. This nitrogen radical has a purple colour which disappears on reaction with antioxidants. The antioxidants neutralize the radical, causing the colour change from purple to yellow or colorless. Thus, the colour can be used to determine relatively accurate antioxidant activity (Garcia et al. 2012).

The DPPH method is given in terms of IC50 (inhibitory concentration 50 %). IC50 indicates the concentration of a substance that will reduce the absorbance of DPPH by 50 %. DPPH is usually given in IC50 µg/ml. A lower IC50 value indicates a higher antioxidant activity. This means that a lower concentration is needed to achieve 50 % inhibition (Dawidowicz et al. 2012).

4.3.3.1.2.2 ABTS method

The ABTS method is also based on the oxidation reaction 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonate) (ABTS) with antioxidants. This radical absorbs light at 734 nm (Antolovich et al. 2002). The prepared solution has blue or green colour. After reaction with antioxidants, the blue or green radical cation ABTS is converted to a colourless. The reaction is monitored spectrophotometrically, and the antioxidant activity can be determined based on it (Martysiak-Zurowska & Wenta 2012).

The ABTS value is usually expressed in units of TEAC (Trolox equivalent antioxidant capacity), which is equivalent to the antioxidant activity of Trolox (vitamin E derivative). TEAC units are most expressed in µmol TEAC/g. The opposite is true for ABTS than for DPPH. A higher ABTS value means a higher antioxidant activity because a gram of sample neutralizes more radical molecules (Silveira et al. 2019).

4.3.3.2. History of meat preservation

The progression of food preservation spans from rudimentary, basic practices such as drying in the sun to advanced methods like ultrasound treatment (Juneja et al. 2017).

Even in prehistoric times, prehistoric people used simple food treatments to keep food fresh and unspoiled for as long as possible. They roasted their food on a fire, dried it in the sun, or kept it in a cold place (Juneja et al. 2017).

The real history of meat preservation probably began in 1500 BC in Mediterranean areas. The climate in the Mediterranean proved ideal for the processing and maturation of meat. Meat treatments, such as drying, smoking, salting, and the utilization of various herbs contributed to an extension of the shelf life (Gonçalves et al. 2021).

Other traditional methods of preservation and preservatives include fermentation, canning, boiling, freezing, salt, sugar, alcohol, or vinegar. These uncomplicated procedures and methods continue to find application in contemporary practices (MacDonald & Reitmeier 2017).

However, relying solely on preservatives is insufficient to prevent MS. Adequate handling and pre-treatment are equally crucial (Dave & Ghaly 2011).

4.3.3.3. Traditional meat preservation in the tropics and subtropics

Traditional preservation methods in the tropics and subtropics are drying, use of salt, or smoke (Kordylas 1990).

The most frequent and preferred method is sun drying. This method is mainly used by small farmers who cannot afford more advanced food preservation technologies due to the high cost. Sun drying is a slow process and therefore may cause deterioration or spoilage during the drying process. In developing countries, 10 % - 40 % of food does not reach the market mainly due to spoilage. Therefore, food preservation plays a major role in the tropics and subtropics.

Simple sun drying (Fig. 3) is the most used method. The produce is spread out so that it can be exposed to the sun, wind, and air. A better but more expensive alternative is dryers, for example, solar dryers (Fig. 4). The crop is largely protected from dust, dirt, or animals.

Also, some of the better dryers need a supply of energy. Most tropical and subtropical areas are not connected to the electricity grid, so energy is obtained from solar and wind power. For most small farmers, investing in more expensive dryers will not be worth their while (Esper & Mühlbauer 1998).

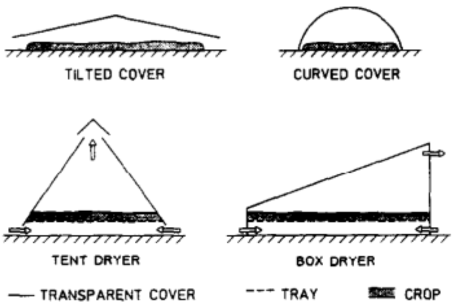

Figure 3. Simple natural convection type dryers (Esper & Mühlbauer 1998)

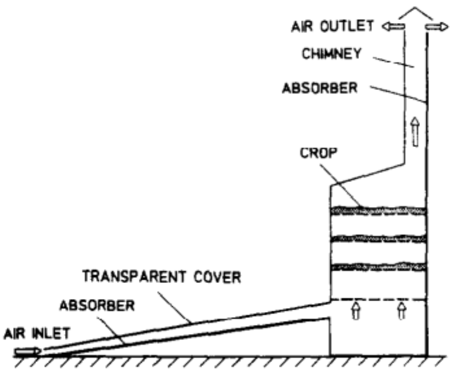

Figure 4. Solar cabinet dryer (Esper & Mühlbauer 1998)

4.4. Plants with high antioxidant and antimicrobial activity from Brazil

Brazil is known for its rich biodiversity, which is not yet fully explored (Carvalho & Conte-Junior 2021). There are many plants with a great antioxidant and antimicrobial effect, suitable for preserving meat or food in general (Silveira et al. 2019). Meat is a big part of the diet of Brazilian people because it contains valuable nutrients for the body (Cabrera & Saadoun 2014). However, it is prone to spoilage, so it is a good idea to extend its shelf life, preferably by using natural preservatives such as PE (Awad et al. 2022).

Table 1. summarizes the plants with high antioxidant and antimicrobial activity in the tropics and subtropics of Brazil. A total of twenty-two plants were found that are used or potentially can be used for preservation. The table includes a basic description of the plant such as English name, Other names, Origin, etc. The DPPH (2,2-difenyl-1-picrylhydrazyl) method were used to compare plants as an indicator of antioxidant activity. Antioxidant activity is important because lipid oxidation is one of the three main causes of MS (Dave & Ghaly 2011). In a large number of plants, the leaf had the greatest antioxidant effect than other parts of the plant. Numerous studies have shown that the leaves contain higher levels of active compounds compared to other parts (Velázquez et al. 2021).

Table 1. Summary of plants with high antioxidant and antimicrobial activity in Brazil

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Cambucá	*Plinia edulis* Vell.	Jabuticaba	native	Myrtaceae	leaf	flavonoids, tannins, saponins	medicinal use, food, wood	3.73 ± 0.12	(Carvalho et al. 2012), (Silveira et al. 2019)
Clove	*Syzygium aromaticum* L.	Indian clove, Clavo	cultivated	Myrtaceae	bud	gallic acid, gallic acid derivatives, eugenol	food preservative, medicinal use, cosmetics, spice, insecticide	4.16 ± 0	(Antolak & Kregiel 2017), (Nassar et al. 2007), (El-Maati et al. 2016), (Widowati et al. 2015)
Cinnamon	*Cinnamomum verum* J. Presl	Ceylon cinnamon, True cinnamon	cultivated	Lauraceae	bark	cinnamaldehyde, cinnamyl alcohol, terpinen-4-ol	food preservative, spice, insecticide, cosmetics, medicinal use	4.34 ± 0.05	(Pathak & Sharma 2021), (Ranasinghe et al. 2013), (Dudonné et al. 2009), (Suriyagoda et al. 2021), (Antolak & Kregiel 2017), (Shan et al. 2005), (Hameed et al. 2016)

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Red angico	*Parapiptadenia rigida* Benth.	Angico-vermelho	native	Fabaceae	bark	tannins, catechin derivatives, proanthocyanidins	medicinal use, gum, wood	4.56 ± 0.03	(Silveira et al. 2019), (Biasi-Garbin et al. 2016), (De Araújo et al. 2014)
Araçazeiro	*Psidium cattleianum* Sabine	*Aracá*	*native*	Myrtaceae	leaf	gallic acid, chlorogenic acid, vanillic acid	food, medicinal use, wood	5.76 ± 0.19	(Zandoná et al. 2020), (Silveira et al. 2019)
Guabiroba	*Campomanesia eugenioides* Blume	Gabiroba	native	Myrtaceae	leaf	flavonoids (flavanones, chalcones, gallic acid)	food, medicinal use, wood, cosmetics	6.07 ± 0.09	(Silveira et al. 2019), (Moura-Costa et al. 2012), (Verruck et al. 2021), (Coutinho et al. 2008)
Green tea	*Camellia sinensis* L.	Tea plant	cultivated	Theaceae	leaf	caffeine, catechins, L-theanine	food, cosmetics, medicinal use	6.81 ± 0.36	(Zielinski et al. 2014), (Jain et al. 2011), (Bastos et al. 2007), (Hasan et al. 2024), (Pereira et al. 2014)

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Yerba Mate	*Ilex paraguariensis* A.St.-Hil.	Mate, Maté, Paraguay tea	native	Aquifoliaceae	leaf	chlorogenic acid, caffeine, theobromine	medicinal use, food, cosmetics	8.98 ± 0.65	(Dudonné et al. 2009), (Heck & De Mejia 2007), (Al-Khateeb et al. 2019)
Brazilian peppertree	*Schinus terebinthifolius* Raddi	Aroeira, Brazilian pepper, Pink pepper	native	Anacardiaceae	leaf	flavonoids, tannins, ascorbic acid	cosmetics, medicinal use, spice, wood, ornamental plant	10.93 ± 0.11	(Da Silva Dannenberg et al. 2016), (Vieira et al. 2023), (Tapanes-Castillo et al. 2017), (da Silva et al. 2017), (Rocha et al. 2018)
Cobblers pegs	*Bidens pilosa* L.	Spanish needles, Cuambú	native	Asteraceae	leaf	kaempferol, gallic acid, catechins	food, medicinal use, natural dye	14.040 ± 0.460	(Falowo et al. 2017), (Kahl 1987), (Morton 1962), (Singh et al. 2017)
Garlic	*Allium sativum* L.	Ajo, Alho	cultivated	Alliaceae	bulb	allicin, alliin, diallyl sulfide	food preservative, medicinal use, spice	15.25 ± 0.16	(Kittisakulnam et al. 2017), (Sofia et al. 2007), (Chang et al. 2013), (Shang et al. 2019), (Liu et al. 2014)

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Achiote	*Bixa orellana* L.	Annatto, Urucum	native	Bixaceae	seed	carotenoid derivatives (bixin, norbixin), terpenoids	spice, food insecticide, natural dye, wood-furniture, cosmetics	15.40	(Viuda-Martos et al. 2012), (Nathan et al. 2019), (Tiyoko Nair Hojo et al. 2014), (Ahmed et al. 2020)
Bitter melon	*Momordica charantia* L.	Bitter gourds, Goya, Karavila	cultivated	Cucurbitaceae	leaf	alkaloids, glycoside, tannins	food, medicinal use, cosmetics, natural dye	28 ± 0.83	(Santos et al. 2010), (Leelaprakash et al. 2011), (Tsai et al. 2014)
Oregano	*Origanum vulgare* L.	Wild marjoram	cultivated	Lamiaceae	leaf	caffeic acid, p-coumaric acid, rosmarinic acid	food preservative, spice, medicinal use, cosmetics	34.5	(Mutlu-Ingok et al. 2021), (Shan et al. 2005), (Ličina et al. 2013)
Moringa	*Moringa oleifera* Lam.	Drumstick tree, Horseradish tree, Miracle Tree, Tree of life	cultivated	Moringaceae	leaf	vitamin A, myrecytin, gallic acid	food, medicinal use, cosmetics, fertilizer, ropes	35.42	(Falowo et al. 2017), (Kashyap et al. 2022), (Ortiz et al. 2022), (Vergara-Jimenez et al. 2017)

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Cashew	*Anacardium occidentale* L.	Caju, Acaju, Cajueiro, Cashew nut	native	Anacardiaceae	fruit	ascorbic acid, carotenoids, anthocyanins	food preservative, food, medicinal use, cosmetics, industrial use, ink, wood	38.29	(Oliveira et al. 2012), (Baskar et al. 2019), (Lopes et al. 2012), (Aracelli et al. 2016)
Long pepper	*Piper longum* L.	Pippali	cultivated	Piperaceae	fruit	piperine, guineensine, pipercide	food preservative, spice, cosmetics, medicinal use	89.18 ± 0.24	(Xavier & Thomas 2020), (Nayeeb Akbar et al. 2014), (Zaveri et al. 2010)
Basil	*Ocimum basilicum* L.	Sweet basil	cultivated	Lamiaceae	leaf	linalool, geraniol, methyl eugenol	food preservative, spice, medicinal use, cosmetics, insecticide	91.31 ± 4.28	(M. Hamad et al. 2017), (Dhama et al. 2023), (Gülçin et al. 2007), (Kavoosi & Amirghofran 2017)
Jambolan	*Eugenia jambolana* Lam.	Jambo	cultivated	Myrtaceae	leaf	carbohydrates, alkaloids, glycosides	food, medicinal use	123.54 ± 0.36	(Santos et al. 2010), (Shankar & Suthakaran 2014)

English name	Latin name	Other names	Origin	Family	Used part	Major bioactive compounds	Use	DPPH IC50 (µg/ml)	References
Culantro	*Eryngium foetidum* L.	Mexican coriander	native	Apiaceae	leaf	chlorogenic acid, tannins, carotenoids	food preservative, spice, medicinal use	131.9 ± 12.5	(Leitão et al. 2020), (Singh et al. 2013)
Turmeric	*Curcuma longa* L.	Saffron	cultivated	Zingiberaceae	root	curcumin, demethoxycurcumin, bisdemetoxicurcumin	food preservative, natural dye, insecticide, medicinal use	155.780	(Zaeoung et al. 2005), (Lourenço et al. 2013), (GÜNERİ 2021), (Choi 2009), (Dahlia et al. 2023), (de Oliveira Filho et al. 2020)
Surinam cherry	*Eugenia uniflora* L.	Brazilian cherry, Ceretô, Cherry of the Rio Grande, Pitanga	native	Myrtaceae	leaf	gallic acid, ellagic acid, myricetin	food medicinal use, wood, insecticide	350	(da Silva et al. 2021), (Santos et al. 2010), (Syama et al. 2019)

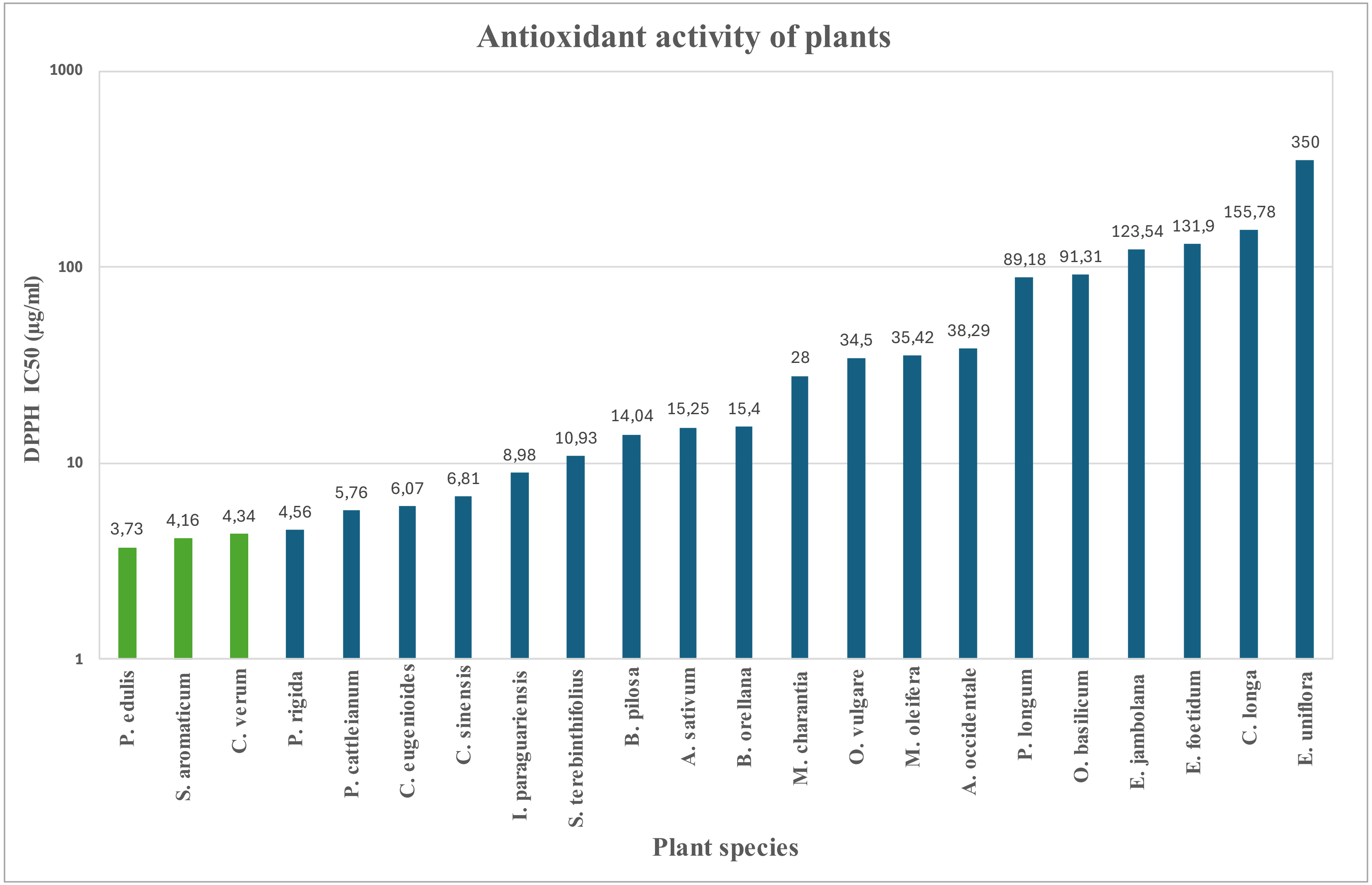

Figure 5. Antioxidant activity of plants in the chart

In the graph shown in Figure 5, the plants are arranged according to the potency of their antioxidant activity as assessed by the DPPH method. The IC50 values indicate the concentration at which half of the DPPH molecules are reduced, which is an indicator of antioxidant activity - the lower the IC50 value, the stronger the antioxidant effect.

The results show that the best antioxidant effect is shown by the plant *Plinia edulis*, which reaches an IC50 value of 3.73 ± 0.12 µg/ml. At the other end of the spectrum, *Eugenia uniflora* is the plant with the less effective antioxidant activity, with an IC50 value of 350 µg/ml.

The three plants that were selected as the best and most suitable for food preservation are highlighted in green in the lower left corner. These plants will be described in more detail in the following chapter, where their specific properties and mechanisms that make them suitable for this purpose will be presented.

4.4.1. Plants with the highest antioxidant activity

In the following chapters, the three plants that had the highest antioxidant activity according to the DPPH method in IC50 (µg/ml) are described more in detail.

4.4.1.1. *Plinia edulis* (Vell.) Sobral

Plinia edulis (Myrtaceae), Cambucá or Jabuticaba is native to Brazil. The plant grows in the Brazilian Atlantic Rainforest and is threatened with extinction due to climate change (Lima et al. 2020). Cambucá typically grows as an evergreen small tree, reaching heights of about five to ten meters.

The plant is used extensively in traditional medicine due to its excellent antioxidant properties. The utilized parts include leaf and fruit. Although it is known and used among the local people, there are not many scientific records of it (Ishikawa et al. 2008). Additionally, it serves as a source of wood, and much use is made of its fruit for food (Carvalho et al. 2012).

Leaf (Fig. 6) with its DPPH IC50 value of 3.73 ± 0.12 µg/ml exhibited the highest antioxidant activity of all the parts. This makes it a great natural alternative in the preservation of meat and food in general (Silveira et al. 2019).

Figure 6. *Plinia edulis* leaf (Donato & de Morretes 2013)

4.4.1.2. *Syzygium aromaticum* (L.) Merr. & L.M. Perry

Syzygium aromaticum, or clove, is a member of the Myrtaceae family. It is an evergreen medium-sized tree, which grows to a height of about ten meters. The leaf, stem, fruit, and bud are used from this tree. But the main reason for cultivating this plant is the unopened flower bud (Fig. 7), characterised by its intense scent and taste. They consist of a longer calyx, which is topped with four calyx leaves and four unopened petals forming a small sphere in the middle (Milind & Deepa 2011). In the picture of figure 8 is a dried flower bud.

This plant is native to Indonesia but is now cultivated almost everywhere, including Brazil. Clove is known as a prized spice, used for many years. Thanks to its great antioxidant and antimicrobial effect, it is a great preservative. Its preservative properties are attributed to its large number of polyphenols, especially the bioactive substance called eugenol. It is also used in medicine, as an insecticide or in cosmetics (Cortés-Rojas et al. 2014).

Bud showed the highest antioxidant value by DPPH, specifically IC50 4.16 ± 0 µg/ml (Widowati et al. 2015).

Figure 7. *Syzygium aromaticum* (Sohilait 2015)

Figure 8. *Syzygium aromaticum* dried flower bud (Kamatou et al. 2012)

4.4.1.3. *Cinnamomum verum* J. Presl

Cinnamomum verum, also known by its old name as *Cinnamomum zeylanicum*, is a member of the Lauraceae family. It is native to Sri Lanka and India, but it is widespread throughout the world. It is an tropical evergreen shrub or tree (Fig. 9), which grows to a height of about ten to fifteen meters (Pathak & Sharma 2021).

The leaf, bark, root, fruit, and flower, all parts of the tree are utilized, making cinnamon a versatile plant with various applications. Its widespread popularity transcends geographical boundaries, as it is extensively utilized worldwide. The ground and dried inner bark of the tree serve as the most common spice derived from it. Large amounts of phenolic compounds, specifically flavonoids, are found in the bark. Additionally, cinnamon holds a significant place in traditional medicine, where it is valued for its digestive and respiratory benefits (Ranasinghe et al. 2013).
The bark (Fig. 10) showed the greatest antioxidant effect. Its DPPH value is IC50 4.34 ± 0.05 µg/ml (Dudonné et al. 2009).

Figure 9. Cinnamomum verum tree (Suriyagoda et al. 2021)

Figure 10. *Cinnamomum verum* bark (MY 2023)

5. Conclusions

The aim of this bachelor thesis was to conduct a literature search on the use of plant extracts to extend the shelf life of meat and meat products in the Brazilian region. Meat is particularly susceptible to spoilage, so it is advisable to use preservatives to extend its shelf life. The main causes of meat spoilage are microbial spoilage, lipid oxidation, and enzymatic autolysis. Furthermore, the aim was to find plants that have high antimicrobial and antioxidant effect. From the data found, a table was created with twenty-two plants and their parts that are most suitable for preservation. Plants that are already used for preservation or that could potentially be used for preservation are listed. The plants have been compared with each other on the basis of antioxidant activity. The antioxidant activity was assessed using DPPH method. 2,2-difenyl-1-picrylhydrazyl (DPPH) is strong nitrogen radical which reacts with antioxidants. The reaction is monitored spectrophotometrically, and the antioxidant activity can be determined based on it. From all the plants, three were selected and described more in detail. The plants with the highest antioxidant activity were *Plinia edulis* Vell. (leaf), *Syzygium aromaticum* L. (bud), and *Cinnamomum verum* J. Presl (bark). This thesis can serve as a basis for further research or use of new plants suitable for preservation. Further research would be good for the practical use of the plants and their safe use as food preservatives.

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