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Packaging and storage of medicinal plants

Embalagens e armazenamento de plantas medicinais

Envasado y almacenamiento de plantas medicinales

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Cristiane Fernandes Lisboa
ORCID: https://orcid.org/0000-0002-9930-8800
Federal University of Viçosa, Brazil
E-mail: cflisboa.engenharia@gmail.com
Evandro de Castro Melo
ORCID: https://orcid.org/0000-0002-1418-8345
Federal University of Viçosa, Brazil
E-mail: evandro.cm@gmail.com
Naiara Cristina Zotti Sperotto
ORCID: https://orcid.org/0000-0003-4536-6850
Federal University of Viçosa, Brazil
E-mail: naiazotti@gmail.com
Mariane Borges Rodrigues Ávila
ORCID: https://orcid.org/0000-0001-6161-977X
Federal University of Viçosa, Brazil
E-mail: avilanane@gmail.com
Luís César da Silva
ORCID: https://orcid.org/0000-0001-6415-6715
Federal University of Viçosa, Brazil
E-mail: silvaluisc@yahoo.com
Catariny Cabral Aleman
ORCID: https://orcid.org/0000-0002-3894-3077
Federal University of Viçosa, Brazil
E-mail: catariny@ufv.br
Joel Camilo de Souza Carneiro
ORCID: https://orcid.org/0000-0002-7539-3799
Federal University of Espírito Santo, Brazil
E-mail: carneirojoel@hotmail.com
Ana Paula de Freitas Coelho
ORCID: https://orcid.org/0000-0002-4144-8966
Federal University of Viçosa, Brazil
E-mail: anapaula.agroufv@gmail.com
Camilla Sena da Silva
ORCID: https://orcid.org/0000-0003-0845-5010
Federal University of Viçosa, Brazil
E-mail: camillasenasilva@gmail.com

Abstract
The therapeutic properties of plants are as old as the occurrence of human species on Earth. Regardless of the purpose of the use of medicinal plants, there is no doubt that there has been an increase in demand for natural methods, representing a major challenge for producers and researchers, regarding standardization and quality control of the raw material, to ensure the quality of the species offered to consumers and the pharmaceutical industry. Despite the increased consumption and consequent expansion of the medicinal plants market, there are few specific studies involving the use of packaging and storage techniques for this type of product. Given the above, this study surveyed concepts involving packaging, as well as characteristics of some polymers commonly used in the storage of plant products, techniques and equipment used in the packaging of food products and work involving the use of modified atmosphere in the medicinal plants storage.
Keywords: Quality; Chemical compounds; Therapeutic properties; Essential oil.

Resumo
O reconhecimento das propriedades terapêuticas é tão antigo quanto a ocorrência dos humanos na Terra. Independentemente da finalidade do uso de plantas medicinais, não há dúvida de que tem havido um aumento na demanda por métodos naturais, representando um grande desafio para produtores e pesquisadores, no que diz respeito à padronização e controle de qualidade da matéria-prima, para garantir a qualidade das espécies oferecidas aos consumidores e à indústria farmacêutica. Apesar do aumento do consumo e consequente expansão do mercado de plantas medicinais, poucos são os estudos específicos envolvendo a utilização de técnicas de embalagem e

armazenamento para esse tipo de produto. Diante do exposto, este estudo levantou conceitos envolvendo embalagens, bem como características de alguns polímeros comumente utilizados no armazenamento de produtos de origem vegetal, técnicas e equipamentos utilizados na embalagem de produtos alimentícios e trabalhos envolvendo o uso de atmosfera modificada na área de armazenamento de plantas medicinais.
Palavras-chave: Qualidade; Compostos químicos; Propriedades terapêuticas; Óleo essencial.

Resumen
Las propiedades terapéuticas de las plantas son tan antiguas como la aparición de la especie humana en la Tierra. Independientemente de la finalidad del uso de plantas medicinales, no cabe duda de que se ha incrementado la demanda de métodos naturales menos agresivos, lo que representa un gran desafío para los productores e investigadores, en cuanto a la estandarización y control de calidad de la materia prima, garantizar la calidad de las especies ofrecidas a los consumidores y la industria farmacéutica. A pesar del aumento del consumo y la consiguiente expansión del mercado de plantas medicinales, existen pocos estudios específicos que involucren el uso de técnicas de envasado y almacenamiento para este tipo de productos. Dado lo anterior, este estudio planteó conceptos relacionados con el envasado, así como características de algunos polímeros comúnmente utilizados en el almacenamiento de productos de origen vegetal, técnicas y equipos utilizados en el envasado de productos alimenticios y trabajos que impliquen el uso de atmósfera modificada en la planta. zona de almacenamiento medicinal.
Palabras clave: Calidad; Compuestos químicos; Propiedades terapéuticas; Aceite esencial.

1. Introduction

The healing power of plants is as old as the appearance of humankind on earth. Early civilizations realized that some species had healing power to combat various diseases, representing an important therapeutic resource (Badke et al., 2011; Benzie and Wachtel-galor, 2015; Cole et al., 2014; Patocka & Almeida, 2017).

The flora with medicinal properties used by the population has generated interest from researchers from different areas to discover new substances or prove the effectiveness of those traditionally used. The big interest is due to the use of many species for medicinal purposes been based on popular knowledge and has not been verified by rigorous scientific study that proves its preventive or curative properties (Dutra et al., 2016; Lima et al., 2006; Patocka & Almeida, 2017).

About 25% of prescription drugs worldwide are derived from plants, and their widespread use is due to the fact that traditional medicines guarantee access to health care for the entire population and have fewer side effects than they do synthetic drugs (Benzie & Wachtel-galor, 2015; Dutra et al., 2016; Who, 2014).

Regardless the reasons for using medicinal plants, there is no doubt that there has been an increase in demand of products obtained naturally. This reality pose a major challenge for producers and researchers with regard to standardization and quality control of raw materials, to ensure the quality of the species offered to consumers and the pharmaceutical industry, as consumption tends to grow worldwide (Cole et al., 2014).

To ensure the quality of the medicinal species offered and the conservation of their therapeutic properties throughout storage, drying of plant material and the use of appropriate packaging are of fundamental importance. Drying process inhibits the development of microorganisms and enzymatic reactions, thereby reducing the deterioration of the active ingredients of interest during storage, in addition to also helping to 'concentrate' the active compounds on a weight basis through water removal. With regard to packaging, it involves and enhances products, from processing to consumption by the customer (Cooksey, 2006).

With the advancement of science, various packaging techniques have been developed and improved. These include vacuum packaging, modified atmosphere and controlled atmosphere. The choice of packaging and storage technique depends on a number of factors, notably the behavior of the physical and chemical characteristics of the product, which must be observed for the choice of packaging and storage technique that best apply to each condition.

Despite the increased consumption and consequent expansion of the medicinal plants market, there are few specific studies involving the use of packaging and storage techniques for this type of product. Given the above, this study surveyed concepts involving packaging, as well as characteristics of some polymers commonly used in the storage of products of plant origin, techniques and equipment used in the packaging of food products and work involving the use of modified atmosphere in the medicinal plants storage.

2. Storage of Medicinal Plants

Brazilians are increasingly betting on herbal treatments and herbal medicines. Between 2013 and 2015 the search for these products in the SUS – Sistema Único de Saúde (Unified Health System) more than doubled, growing 161%. In 2013 about 6,000 people sought a primary care pharmacy to receive the supplies; In 2015 this demand went to almost 16,000 thousand people. The initiative, created by the Ministry of Health to ensure safe access and rational use of medicinal plants and herbal medicines in the country, is already present in about 3,250 units in 930 Brazilian municipalities (SUS, 2016).

To meet the growing demand for medicinal plants and herbal products with quality products, the raw material must go through the post-harvest process before being sent to the final consumer. This process is necessary since the high water content of fresh plants leads to the rapid degradation of plant material as a whole, resulting in a reduction in their final quality.

The postharvest of medicinal plants is of great importance in the production chain, due to its direct influence on the quality and quantity of active ingredients. Among the post harvest processes, drying and storage are fundamental to keep the product with the physical and chemical characteristics closer to those found in the fresh plant.

The storage and conservation of medicinal plants aim to prevent deterioration of their quality, maintaining the qualitative and quantitative aspects after drying, by developing ideal conditions of temperature and relative humidity, avoiding the attack of microorganisms, fungi and insects during the storage period. During storage, metabolic activity should be reduced, making medicinal plants less susceptible to deterioration. This can be achieved by reducing the product's water content to adequate levels, cooling or using a modified atmosphere in the system in which medicinal plants are stored (Masand et al., 2014; Silva et al., 2013).

The storage period indicated for medicinal plants is one year, but a longer shelf life may be accepted if the manufacturer presents stability test results that guarantee the maintenance of the product characteristics in the proposed period (Brasil, 2010).

Medicinal plants are often stored for long periods before being used as raw material for the manufacture of various products (Sourestani et al., 2014). However, improper storage may result in physical, chemical and microbiological changes (Mayuoni-Kirshinbaum et al., 2013; Peter, 2006).

Storage time may influence the concentration of chemical components the active compounds. Rowshan, et al. (2013) evaluated the influence of different storage conditions, refrigerator (-4 °C), freezer (-20 °C) and room temperature (25 °C), on the composition of the essential oil of *Thymus daenensis* Celak shoots. They observed that freezer storange kept the percentage of essential oil components closer to that observed at the beginning of storage, storage at room temperature in addition to not impairing the quality of the essential oil has considerably increased the percentage of some important components such as thymol (from 27.4 to 34.7%) and carvacrol (from 28.8 to 35.7%). This was probably due to the volatilization of lighter monoterpenes, remaining the heavier ones (such as thymol and carvacrol).

Jesus et al. (2016) studying the effect of two conditioning temperatures (ambient: average 32ºC; and freezer: -20 ° C) during storage on the essential oil quality of *Hyptis pectinata* L. Poit., Also observed variation in the concentration of the chemical constituents of this oil. Storage of the essential oil at room temperature resulted in higher concentrations of β-elemene, α-copaene, germacrene-D, caryophyllene oxide and (E, E) -α-farnesene and lower concentrations of α-humulene and β-caryophyllene when compared to the results obtained from the storage of essential oil in the freezer.

Another important factor to consider when storing medicinal plants is the type of packaging. The packages commonly used for storing plant leaves today are: paper bags, polyethylene bags, cardboard boxes and double kraft paper bags with an inner layer of non-toxic polyethylene (Corrêa Junior et al., 2006).

Using polypropylene bags to package dried samples of whole and ground *Ocimum selloi* leaves, and evaluating the effect of storage time on yield and chemical composition of this plant's essential oil, Costa et al. (2009) found a marked reduction in the essential oil yield of both whole and ground leaves over one year of storage. However, the yield obtained from whole leaves was significantly higher than that of ground leaves.

In general, throughout the evaluated period, methyl-chavicol, the major compound, was present with a higher relative concentration in whole leaves at time zero than in ground leaves, 93.98 and 97.89, respectively, showing a decreasing behavior over the storage time.

Chaliha et al. (2013) compared the effect of alternative high barrier packaging (LDPE, linear low-density polyethylene; PET, polyethylene terephthalate/ CPP, casted polypropylene; coated PVDC, polyvinylidene chloride; and PET / PET / Foil / LDPE) during storage of *Syzygium anisatum*, *Tasmannia lanceolata* and *Backhousia citriodora*. They concluded that traditional packaging LDPE showed higher loss of volatile compounds during storage of *Backhousia citriodora* (87% loss), followed by PET / CPP coated PVDC (58% loss) and PET / PET / Foil / LLDPE (23% loss) storage.). The volatile losses by *Syzygium anisatum* and *Tasmannia lanceolata* during storage in PET / CPP and PET / PET / Foil / LLDPE coated PVDC was less than 30%.

The method used to store medicinal plants throughout the storage can also affect the essential oil quantitatively and qualitatively. Ebadi et al. (2017), investigating the effect of packaging methods (air, nitrogen or vacuum packing) during storage, in the content and composition of essential oil of *Lippia Citriodora* Kunth. observed that, the leaves of *Lippia citriodora* Kunth. stored with nitrogen showed higher essential oil content and higher percentage of limonene at the end of eight months of storage. However, the leaves stored under vacuum preserved a higher percentage of citral in the same period.

Investigating the effect of modified atmosphere packaging (LFO-160: 130 mL O_2.$kg^{-1}h^{-1}$; e ML-7525: 510 mL O_2.$kg^{-1}h^{-1}$) during storage of *Hippophae rhamnoides* Linn, Li et al. (2015) observed that the samples stored in modified atmosphere packaging presented higher antioxidant activity, especially those in LFO-160 packaging.

In the current context, in which, there is a growing demand for herbal medicines, due to fewer side effects and healthier benefits, storage is an important step. If done in an appropriate way, can overcome the seasonality of production, offer a safe product to the consumer and maintain the quality of the active principles for a long period.

3. Permeability and Permeability Rate of Packaging: Concepts

The packages have intermolecular spaces through which the process of permeation of gases and vapors occurs, and this process occurs in three stages. Step 1 involves sorption and solubilization of the permeant on the material surface; Step 2 involves the diffusion of the permeant through the material due to the action of a chemical potential gradient; Finally, step 3 involves desorption and evaporation of the permeant on the other side of the material (Sarantópoulos et al., 2018).

With regard to the permeability rate, the capacity of a packaging material to resist the passage of gases and vapors, fats and the light transmission is defined as a barrier. The gas barrier of a package is evaluated by the amount of gas passing through a unit of surface area of the packaging per unit of time, at certain temperature, relative humidity and under certain partial pressure gradient of the gas-test (Sarantópoulos et al., 2018).

Equation (1) describes the permeation of gases and vapors in stationary state polymers at a constant temperature.

$$\frac{dq}{dt} = D.S.A\frac{(\rho_1 - \rho_2)}{e} \quad (1)$$

Where:

$\frac{dq}{dt}$ = Permeant Flow Rate;

D = Diffusivity coefficient;

S = Solubility coefficient (characteristic of the polymer-permeant system);

A = Permeated area;

$(\rho_1 - \rho_2)$ = Partial pressure gradient of the permeant between the surfaces (1 and 2) of the polymeric material; and

e = Thickness of polymeric material.

The permeability coefficient, this can be described by the equation (2):

$$P = D.S \quad (2)$$

Where:

P = Permeability coefficient.

Finally, for all polymer-permeant systems, the permeability coefficient has a temperature dependence, according to the Arrhenius model, expressed in equation (3):

$$P = P_0.e^{(-Ep/RT)} \quad (3)$$

Where:

P_0 = Constant pre-exponential factor, independent of temperature;

E_p = Activation energy for permeation;

R = Universal constant of ideal gases; and

T = Absolute temperature.

4. Permeability Rate of Polymers

The plastic materials have been the most used in the last years in the production of packaging due to its lower cost and for presenting characteristics that favor the conservation of food. However, consumers are increasingly prioritizing products that are packaged with sustainable materials and have less environmental impact.

Plastics can be defined as flexible sheet materials possessing, in their molecular structure, long and flexible molecules interconnected in a strong and non-brittle network. These are stable structures called polymers. Regarding the polymer concept, the word originates from the Greek poly (many) and mere (repeating unit). A polymer is a macromolecule composed of many tens or hundreds of thousands of repeating units called Mere, linked by covalent bonds. The polymers are obtained through the polymerization reaction of the monomers, that is, a molecule with a (mono) repeating unit (Canevarolo Junior, 2006).

The differences in the chemical constitution of the monomer units, in the structure of the polymer chains and in the interrelationship of the chains, determine the different properties of the various polymeric materials (Robertson, 2006).

Some of the most used polymers in the manufacture of food packaging are low-density polyethylene (LDPE), High-density polyethylene (HDPE), polyamides (PA) polymers known as nylon, polyethylene terephthalate (PET) and chloride Polyvinylchloride (PVC).

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Polyethylene may present different ramifications, and low-density polyethylene has approximately 50% crystallinity, while high-density polyethylene has about 80% (Coutinho et al., 2003). The presence of large ramifications in low density polyethylene hinders the crystallization process, making the polymer less crystalline and with less perfect Crystallizs (Canevarolo Junior, 2006).

With regard to nylon, they are semicrystaline plastics and belonging to a class of polymers widely used for engineering applications due to the combination of some properties, such as: dimensional stability, good impact resistance without Notch, excellent chemical resistance and easy processing (Huang et al., 2008).

The nylon has low permeability to oxygen, however, they are highly hygroscopic and sensitive to the notch, that is, they are ductile when not notched, but fracture in a fragile way when notched, due to their low resistance to the propagation of Broken (E313-10, 2010).

The most common nylon is nylon 6 and 6.6 nylon. The number next to the name refers to the amount of carbon atoms existing in the monomer. Therefore, it is observed that the polymerization involves the reaction between one or two monomers, depending on the type of nylon to be processed (Jorge, 2013).

Polyethylene terephthalate (PET) is obtained by the process of polymerization by stages, mainly starting from the esterification reaction of terephtalic acid (TPA) with ethylene glycol (EG) at a temperature between 240 ° C and 260 ° C and with a pressure between 300 and 500 kpa (Awaja and Pavel, 2005).

The PET has high melting temperature (on average 265 ° C) and high hydrolytic stability due to the presence of aromatic rings in the main chain (Paci and La Mantia, 1999; Romão et al., 2009).

Finally, Polyvinylchloride (PVC) can be obtained from acetylene or ethylene. Acetylene comes from calcium carbide, but the most viable use is that of ethylene derived from petroleum, with reaction of adding chlorine atoms to acetylene molecules (Jorge, 2013).

There are several units of measurement that can be found when talking about a permeability coefficient. Table 1 shows some factors to convert permeability coefficients to several units. These conversions will be of great importance, since the examples of the permeability coefficient for the polymers in this study will be given in the mL unit (STP) cm cm^{-2} s^{-1} cm Hg^{-1}.

Table 1. Factors for converting permeability coefficients to multiple units.

Units	Multiplication factor for obtaining P in [mL(STP) cm cm^{-2} s^{-1} cm Hg^{-1}]
[mL(STP) mm cm^{-2} s^{-1} cm Hg^{-1}]	1.00×10^{-1}
[mL(STP) cm cm^{-2} s^{-1} atm^{-1}]	1.32×10^{-2}
[mL(STP) mil cm^{-2} day^{-1} atm^{-1}]	3.87×10^{-14}
[mL(STP) mil 100 in^{-2} day^{-1} atm^{-1}]	5.99×10^{-13}
[mL(STP) mm m^{-2} day^{-1} kPa^{-1}]	2.33×10^{-12}
[in^3(STP) mil 100 in^{-2} day^{-1} atm^{-1}]	9.82×10^{-12}
[mL(STP) cm m^{-2} day^{-1} atm^{-1}]	1.52×10^{-11}

Source: Yasuda and Stannett (1975).

Table 2 shows the values of the O_2 and CO_2 permeability coefficient for some polymers.

Table 2. Permeability coefficient (P) for various polymers and for permeating gases O_2 and CO_2.

Polymer	P x 10^{11} [mL(STP) cm cm^{-2} s^{-1} (cm Hg^{-1})]	
	O_2 30°C	CO_2 30°C
Low Density polyethylene	55.00	352.00
High Density polyethylene	10.60	35.00
Polyamides (nylon 6)	0.38	1.60
PET	0.22	1.53
PVC	0.053	0.29

Source: Adapted from Stannett et al. (1962).

Table 3 shows that low-density polyethylene has a higher permeability coefficient for O_2 and CO_2, followed by polymers: high density polyethylene, polyamides, PET and PVC. Thus, for the use of modified atmosphere in medicinal plants, from the point of view of the O_2 and CO_2 permeants, the polyamides, PET and PVC packaging would be interesting alternatives, however, polyamides have advantages in relation to PET and PVC, as it is a material with good dimensional stability, good impact resistance, excellent chemical resistance and easy processing.

With regard to the rate of transmission of water vapor, it can be observed in Table 3 some rates of water vapor transmission for some polymers.

Table 3. Water vapor transmission rate at 38 °c and 95% relative humidity.

Polymer	Baud rate (g mm M-2 day-1) x 10-2
Polyamides (nylon 6)	634.0 – 863.0
Low Density polyethylene	31.5 – 59.0
PET	31.5 – 59.0
PVC	19.7 – 31.5
High Density polyethylene	11.9 – 19.7

Source: Adapted from Ashley (1985); Karel (1975).

Polyamides have the highest rate of water vapor transmission, followed by low-density polyethylene, PET, PVC and high-density polyethylene. The fact that polyamides present a higher rate of water vapor transmission is due to its hygroscopic behavior, so it is not recommended to store medicinal plants in polyamides packaging under conditions of high relative humidity (above 70%). Under high relative humidity conditions, high-density polyethylene packaging would be best recommended for having lower water vapor permeability rate.

Given the above, the process of vapor permeability through the polymers depends on a number of factors, and the contact of these permeates with the product can significantly affect its quality. Thus, the permeability rate of the polymers should be one of the factors to be taken into consideration when choosing the most appropriate packaging to store the food product that is working. We will see clearly and applied the influence of packaging characteristics on the quality of medicinal plants in section 6.2.

5. Interaction Between Stored Plant Material, Packaging and Environment

The degree of protection required by a foodstuff is a key factor in the selection of packaging material and design. Thus, the degree of protection has a direct influence on the interactions between the environment, packaging and the stored product. The following are enumerated the interactions between the environment, packaging and stored product (Linssen and Roozen, 1994).

i: Oxygen: The oxygen permeation of the environment to the inside of the packaging causes oxidation, alteration in the color, flavor and respiration of the medicinal species;

ii: Carbon dioxide: The permeation of water vapor from the inside of the packaging to the environment causes changes in respiration and loss of carbonation;

iii: Water vapor: The permeation of water vapor from the inside of the casing to the environment causes dehydration and texture change;

iv: Aroma: The aroma permeation of the environment to the inside of the packaging causes a change in aroma and/or flavor;

v: Light: The permeation of ambient light to the inside of the packaging causes degradation of color, flavor and nutrients.

vi: Migration of packaging components: causes changes in aroma and/or flavor and toxicity; and

vii: absorption by packaging: causes loss of aroma and/or flavor.

In general, the protection offered by the packaging is defined in terms of a variety of factors that can affect the quality attributes of the medicinal species from the moment the product is placed in the container until the time of consumption. Environmental parameters such as oxygen, nitrogen, carbon dioxide, water vapor or aromas, in direct or indirect contact with the product are influenced by the packaging properties (Singh and Heldman, 2001).

Many stored products are sensitive to the concentration of oxygen in the conditioning environment due to deterioration associated with oxidation (Sarantópoulos and Cofcewicz, 2016). In the specific case of medicinal plants, studies on this type of interaction are still insipient and deeper studies are needed on these interactions, and preferably on a large number of species to verify with greater precision the behavior of the interactions between the environment, packaging and the stored product.

5.1 Main permeants of interest in the packaging of medicinal plants

According to Silva et al. (1999), the loss of chemical compounds from medicinal plants occurring after harvesting is due to several reasons, including degradation by metabolic processes, hydrolysis, degradation from enzymatic action, oxidation, fermentation, heat, microbiological contamination or the presence of light.

When stored in inadequate packaging, medicinal plants may be affected by permeating gases that are capable of triggering losses of active ingredient by the processes described above. The main permeants that can affect the physical and chemical quality of medicinal plants are oxygen, carbonic dioxide gas and water vapor.

Oxygen in contact with food allows the growth of deteriorating aerobic microorganisms (Floros and Matsos, N.D.; Mahajan et al., 2014), thus, in concentrations close to those found in the atmosphere, could provide the development of microorganisms and consequently the degradation of the medicinal species.

With regard to carbonic dioxide gas, due to its bacteriostatic and fungicide action, it is used as an antimicrobial agent in packaging with modified atmosphere for perishable products. In products that have high water activity, such as fruits, fresh vegetables and fresh medicinal plants, in certain concentrations can minimize respiration and, consequently, the senescence of the vegetables. This implies that, for these categories, their loss through the packaging compromises the preservation of the product, so its presence in the packaging must be associated with good gas barrier, so that it can remain dissolved in the product and/or around it inside the package (Sarantópoulos et al., 2018; Sivertsvik et al., 2002).

With regard to carbonic gas, due to its bacteriostatic and fungicide action, it is used as an antimicrobial agent in packaging with modified atmosphere for perishable products. In products that have high water activity, such as fruits, fresh vegetables and fresh medicinal plants, in certain concentrations can minimize respiration and, consequently, the senescence of the vegetables. This implies that, for these categories, their loss through the packaging compromises the preservation of the product, so its presence in the packaging must be associated with good gas barrier, so that it can remain dissolved in the product and/or around it in the Inside the package (Sarantópoulos et al., 2018; Sivertsvik et al., 2002). Thus, carbonic gas can bring benefits in the conservation of medicinal species, reduce the process of respiration of the product, and consequently the metabolic processes, similarly to what occurs during drying.

Many products require packaging that to water vapor permeation to avoid gain or loss of moisture. In foods with low water activity, as in the case of dry medicinal plants, the moisture gain favors microbial growth, enzymatic action and non-enzymatic browning (Sarantópoulos et al., 2018) that favor the degradation of active principles of medicinal interest.

By virtue of what has been observed, oxygen, carbon dioxide and water vapor are permeant that can provide important changes in the quality of medicinal plants throughout the storage. Therefore, these should be taken into consideration during the choice of the packaging material that will be used because, this should prevent in the most efficient way possible the passage of these gases, ensuring the maintenance of the quality of the product during the storage period.

6. Types of Packaging

When talking about the packaging of food products and medicinal plants, the most common techniques to be found are: vacuum, modified atmosphere and controlled atmosphere. These packaging methods are efficient in maintaining the quality of these products are applied according to the conservation needs and the added value of the product to be stored.

The vacuum packaging is defined as the packaging of the product in gas-barrier packaging, in which the air is removed to prevent the oxidation caused by the polyphenoloxidase activity, the product color change and the growth of microorganisms which are the main responsible for promoting deterioration of products during storage. According to most researchers, this type of packaging is considered a form of packaging in modified atmosphere, since, when removing air, the atmosphere inside the package is modified (Gorris and Peppelenbos, 1992; Mantilla et al., 2010). According to Church (1994), vacuum packaging has the advantage of being a simple technique, however, the compression that causes the material can change its original shape.

As regards the modified atmosphere, it is based on the packaging of the product in gas-barrier packaging, where the gaseous composition inside the package is modified at the time it is sealed and changes dynamically, depending on the respiration of the product and the permeability rate of the film. It is desirable that the natural interaction that occurs between the respiration of the product and the packaging, generates an atmosphere with low oxygen concentration (O_2) and/or high concentration of carbon dioxide (CO_2). Thus, it provides a reduction in the growth of microorganisms, reduces respiration and ethylene production, reduces physiological changes, and inhibit chemical, enzymatic and microbiological mechanisms associated with deterioration of the product. Thus, other chemical or thermal processes can be avoided, such as freezing, dehydration and sterilization (Church and Parsons, 1995; Fonseca et al., 2002; Gorris and Peppelenbos, 1992; Jayas D.S. A4 - Jeyamkondan, S., 2002; Kader et al., 1989; Parry, 1993; Saltveit, 1997).

The modified atmosphere can be divided into passive and active. The passive is the result of an atmosphere created passively within the packaging by the respiration of the product, translated by the use of oxygen and release of carbon dioxide (Brackmann and Chitarra, 1998), while the active is the one provided by the injection of composition known at the time the product is packaged (Lana and Finger, 2000).

Barbosa et al. (2016), evaluating the hydrocooling and storage in a passive modified atmosphere of *Mentha piperita* L., observed that the packaging of polyethylene terephthalate (PET – perforated and non-perforated) was effective to increase shelf life of *Mentha piperita* L. and the hydro cooling coupled with the use of unperforated packaging was the most efficient method to maintain the postharvest quality of this species.

Mattos et al. (2013) investigated the effect of packing in modified atmosphere active in the quality attributes and physiological response of *Lactuca sativa* L. They stored the product in polypropylene bags (PP) using two active modified atmospheres (5% O_2 + 5% CO_2 + 90% N_2; and 2% O_2 + 10% CO_2 + 88% N_2) and a passive modified atmosphere (ambient-control air). They concluded that the active modified atmospheres did not presented significant effects on the quality attributes and physiological behavior of fresh *Lactuca sativa* L., considering the conditions in which the experiment was carried out.

With regard to conditioning in controlled atmosphere, this is based on the reduction of O_2 levels and increased CO_2 levels of the environment in which the product is packaged, providing a reduction in respiration rate and consequently, its process of ageing and loss of quality. Moreover, it is a dynamic system, where the composition of the atmosphere that surrounds the product is monitored and kept constant under specific conditions of temperature, relative humidity, partial pressures of O_2 and CO_2. Commonly, it applies to bulk storage of fruits and vegetables with seasonal production in order to promote product supply over a longer period. The application is carried out in transport container or storage chamber, where the temperature, relative humidity and the composition of the gas are kept constant, controlled and monitored throughout the storage period. These parameters should be adequate to the type and stage of maturation of the product stocked (Brackmann and Chitarra, 1998; Gorny and Kader, 1996; Gupta et al., 2009; Lana and Finger, 2000; Wright et al., 2015).

In view of the observed aspects, all the packaging methods mentioned above provide benefits in the maintenance of the postharvest quality of products of plant origin, and the use of these methods can provide better maintenance of postharvest quality of medicinal plants during storage.

6.1 The methods and equipment employed for the establishment of modified atmosphere environments

Historically, the packaging for food products has evolved in response to a variety of industry and consumer expectations. The four basic functions of food packaging are: containment, protection, communication and convenience (Krochta, 2007; March, 2001; Robertson, 2006; Yam et al., 1999).

The containment function literally refers to containing the product, causing the packaging to serve as a container. The protection function must ensure the preservation of the product against shocks, vibrations and compressions that will happen during transport, distribution and handling, and prevent tampering or loss of integrity, accidental or intentional through opening evidence systems (seals, lids with rupture ring, lids with vacuum indicator knob, etc.). As regards the communication function, the packaging is a vehicle of information, so its function is to transmit information such as, name, product type, quantity, date of manufacture and validity, nutritional information, storage instructions preparation and use, and allow traceability of the product. Finally, the convenience function refers to easy opening, such as metering caps and the possibility of closing between uses. Possibility of heating or cooking and serving in the packaging itself; use in microwave ovens. Allow the combination of different products such as yogurt and cereals and be suitable for different occasions of consumption, as in sports situations and in different quantities and individual doses. In this role, less technical and more related aspects of marketing and communication can be included, as the packaging should retain attention and seduce the buyer at the point of sale (Jorge, 2013; Singh & Heldman, 2009).

Innovations in food packaging have created a series of new terms associated with the paper packaging in improving the safety, service life and convenience of the food product, among them is the modified atmosphere packaging system.

With regard to active modified atmosphere, some methods can be used to establish this type of environment, among them we can cite: the reduction of oxygen concentration (O_2) or increase in the concentration of carbon dioxide (CO_2), nitrogen (N_2), ozone (O_3), and also the combination of the methods cited above.

As previously reported in Topics 4 and 5, O_2 is responsible for many undesired reactions in products of plant origin. Due to the negative effects, O_2 is generally reduced or avoided in the packaging in active modified atmosphere. However, its presence in small quantities is necessary for some products, for example, for many fruits and vegetables, allowing the basic processes of aerobic respiration; and red meats, keeping the red color of fresh meats. (Mahajan et al., 2014).

Despite the negative effects for several products, the use of O_2 at high concentrations in the packages in active modified atmosphere serves as an inhibitor of the growth of anaerobic bacteria (Pantazi et al., 2008) and assists in the conservation of characteristics of some plant products.

Another method used in the environment of active modified atmosphere is the increase of CO_2 concentration. CO_2 is the main responsible for the bacteriostatic effect on microorganisms that cause food deterioration in packages in active modified atmosphere (Sivertsvik et al., 2002).

According to the Food and Drug Administration (FDA, 2018), CO_2 is an natural antimicrobial, nontoxic and recognised as a substance GRAS (Generally Recognized as Safe). The inhibitory effect of the modified atmosphere package is directly related to the amount of CO_2. The solubility of this gas is indirectly proportional to the storage temperature, so low temperatures have a synergistic effect for the bacteriostatic action of CO_2 (Church & Parsons, 1995).

There are some explanations for the mechanism of CO_2 inhibition on microorganisms, they are: changes in the function of the cell membrane, interfering in the transport of ions; Dysfunctions in nutrient absorption; Inhibition and/or reduction of enzyme reactions; Changes in intracellular pH and direct modifications in the physicochemical properties of proteins within the microorganisms. The bacteriostatic effect of CO_2 is a combined action of all these mechanisms and occurs with different intensities in all bacterial species (Brandenburg & Zagory, 2009; Jay, 2005; Sivertsvik et al., 2002; Wolfe, 1980; Yuan, 2003).

The use of N_2 is also common in modified atmosphere packaging, being an inert and tasteless gas. This gas presents low solubility in water and lipids, not being absorbed by the food, which makes it a filling gas, avoiding the collapse of the packaging by the absorption and dissolution of CO_2 in the food matrix. Nitrogen is also used as a substitute for oxygen in the packaging, inhibiting microbial growth and oxidation-sensitive products, as an alternative to vacuum packaging (Church, 1994; Kerry et al., 2006; Patsias et al., 2006; Phillips, 1996; Schirmer & Langsrud, 2010; Sivertsvik et al., 2002; Soccol & Oetterer, 2003).

In recent years, O_3 has been gaining prominence in post-harvest studies because it is a sanitizer with high oxidation potential that can come into contact with food. Ozone is the second most powerful oxidant agent losing only to fluoride (F^{+2}) (Da Silva et al., 2011; Russel et al., 1999). Thus, the high oxidation power of ozone imprints high capacity of disinfection and sterilization allowing the sanitizing action to occur in shorter contact time and concentration (Da Silva et al., 2011).

O_3 is a gas partially soluble in water and, increases its solubility as the temperature decreases (Da Silva et al., 2011; Langlais et al., 1991; Wysok et al., 2006).

With the advancement of new technologies, the use of ozone has expanded considerably, nationally or internationally, in different areas of application, as in the treatment of domestic and industrial effluents, pulp bleaching processes and treatment of drinking water, among others. However, new segments of ozone applications are mainly developed in the areas of food processing and agriculture (Rozado et al., 2008).

On the other hand, depending on the concentration of O_3 applied besides the sanitizing action, it can promote nutrient losses or alter the sensory quality of the food, because if the concentration is high, it may cause oxidative damage, resulting in the production of unpleasant odor and alteration in the coloring of the food (Da Silva et al., 2011; Kim et al., 1999).

With regard to equipment used for the establishment of modified atmosphere, there are in the market specialized companies that manufacture generators of O_2, CO_2, N_2 and O_3. The working principle of the O_2 and N_2 generators is based on pressure balance adsorption, which allows the separation of some gas species from a gaseous mixture under pressure. The generation of CO_2 is based on the combustion of fuels, the propane being the most used fuel for the equipment available in the market. With regard to the O_3 generator, the capitation of ambient air occurs, and by means of corona discharge, which is the most industrially used method, there is the breakdown of the O_2 molecules and the transformation of these into O_3.

When it comes to packaging in modified atmosphere, the most common in the market is to acquire the gas cylinders of specialized companies that commercialize gaseous mixtures with the most diverse combinations. However, in the case of N_2 and O_3 there is the possibility of producing these gases in the industry itself, since in the market there are efficient industrial equipment that meet the demand of the industry by these gases, reducing costs and the dependence of the industry with the Supplier.

Because of the aforementioned facts, there are several methods that can be used to establish environments in modified atmosphere, and the product characteristics must be observed before choosing the method, due to the possibility of negative interaction between the product and the environment in modified atmosphere.

6.2 Main physical and chemical characteristics of medicinal plants to be preserved throughout storage

The water content of medicinal plants is directly related to the triggering of deteriorating processes such as enzymatic reactions and microbial degradations, thus storing this product with low water content avoids the degradation of its chemical properties, and consequently prolongs the life of the plant material (Chan et al., 2015; Chin & Law, 2010; Mujumdar and Law, 2010; Park et al., 2014). For the storage to be efficient and maintain the quality of the product similar to the beginning of the packaging, it is desirable to have stability of this characteristic throughout the storage period.

With regard to coloration, this is an important sensory attribute, as the consumer also makes purchase decisions based on the appearance of the product. Moreover, it is an attribute that is used as an index of maturation of all fruits and many vegetables, and also shows the occurrence of mechanical damage or injury (Kakiomenou et al., 1996). In the case of medicinal plants, the consumer has preference for coloring similar to the *in natura* product, by associating it with a fresh and higher quality product. Given the importance of the coloring of the product in the purchasing decision of the consumer, it is desirable that the green coloration of the leaves of the medicinal plants remain stable throughout the storage.

Essential oils and bioactive compounds contained in medicinal plants are also an important attribute to be conserved during storage, both quantitatively and qualitatively. Essential oils are secondary metabolites produced by plants, which confer resistance to adverse conditions, such as climatic variation and insect and micro-organism attack (Cole et al., 2014). These substances are mainly used by the cosmetic and herbal medicine industry, requiring adequate storage conditions before and after processing so that no quantitative and qualitative losses occur.

Given the above, the water content, coloration, bioactive compounds are variables of paramount importance in monitoring the quality of medicinal plants throughout the storage.

6.3 The damage potentiated the quality of medicinal plants packaged in modified atmosphere

In general, the gases that had their characteristics described in this study, only O_2 and O_3 can cause damage to the medicinal plants stored in packages with modified atmosphere.

The oxygen at concentrations close to those found in the atmosphere could provide the development of microorganisms (Floros & Matsos, 2005; Mahajan et al., 2014) and consequently the degradation of medicinal plants. While O_3, by having high oxidant action and whitening action, could cause both the degradation of the compounds of interest present in the essential oil, and to modify the color of the medicinal plants, being the color an important sensory attribute, because the consumer also makes purchase decisions based on the appearance of the product.

To prevent undesired permeant gases from contacting medicinal plants or the desirable gaseous mixture to keep in touch with the product for a long period, one should choose a good quality film. In addition, the temperature and relative humidity conditions of the site in which the product will be stored must be observed at the time of the film's choice, since they are factors that directly interfere with the permeability rate of the packaging and may cause quality loss of stored product (Sarantópoulos & Cofcewicz, 2016).

In view of the above, the success of the modified atmosphere is related to the quality of the films used in the filling of the product, which must have the ability to maintain the atmosphere created, during the longest possible period. Besides having resistance to abrasion, rupture and perforation; adequate thickness in order to avoid micropores; permeability to gases and water vapor, and the ability to maintain the sealing integrity of the packaging, are essential to prolong the service life of the product. Most of the films applied are made up of several layers and combinations of the polymers mentioned above in order to improve the packaging efficiency (Mangaraj et al., 2009; Paul & Clarke, 2002).

It is noteworthy that the packaging in modified atmosphere does not improve the initial quality of the product, maintaining, in ideal conditions, the quality existing at the time of sealing the packaging. This causes the harvesting, handling and processing conditions to be decisive for the quality of the final product (Brandenburg & Zagory, 2009).

Taking into consideration all aspects observed, the use of modified atmosphere prolongs the useful life of products of plant origin and can provide that medicinal plants maintain their physical and chemical quality for a longer period. In addition, the technology for production of modified atmosphere packaging has evolved a lot in recent years, enabling the use of modified atmosphere packaging in industrial scale for medicinal plants.

7. Final Considerations

In the current context, in which there is growing demand for traditional medications, because they have fewer side effects and are considered healthier, storage is an important step, which is done appropriately, can overcome the seasonality of production, offer a consumer safe product and maintain the quality of active principles for a long period of time.

Conflict of Interest and Ethical Standards

All authors declare no conflict of interest, and this article does not contain studies with human or animal participants performed by any of the authors

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Conflict of Interest and Ethical Standards

All authors declare no conflict of interest, and this article does not contain studies with human or animal participants performed by any of the authors.

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