Drying Techniques in Medicinal and Aromatic Plants and Its Impact on Quality

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Abstract: Drying is a very basic fundamental method of food preservation. Moisture is removes from the food materials during drying which check the growth of various microorganisms as well as restricts the metabolic changes and ensures the longer shelf life without deterioration of quality. Sun and shade drying are most commonly used drying techniques and very economic, however, mechanical types of drying techniques have number of advantages at commercial level. Each and every drying technique has its own goodness and the maximum retention of quality is dependent on the nature of dried materials. Medicinal and aromatic plants (MAPs) are popularly known for its presence of specific bioactive compounds and demand of plant-based medicine are increasing exponentially worldwide. Quality maintenance is most concern in this plant group, but due to the limitations or lack of knowledge in post-harvest process including drying the quality is not maintained as required in pharmaceutical industries or ayurvedic medicine. This chapter is focuses on the recent advances in the field of various drying techniques used in MAPs and its impact on conservation of bioactive compounds.

Key words: Drying, Medicinal and aromatic plants, Bioactive compounds, Conventional drying, Mechanical drying

1. Introduction

Drying is one of the oldest and most traditional methods of food preservation known to humankind. It involves preserving food plants by allowing them to dry naturally under the sun or in naturally dry air. This process effectively reduces the moisture content in the food, which helps to inhibit the growth of microorganisms, thus extending the shelf life of the food product. The technique of sun-drying has been used for centuries in various cultures to preserve fruits, vegetables, and even meat, ensuring a stable food supply during times of abundance for consumption during scarcity. Drying, also known as dehydration, is the process of removing water through evaporation from a solid or liquid food materials. The main goal is to obtain a solid product with a significantly reduced moisture content (Berk, Z. 2018). Drying is the predominant and fundamental post-harvest preservation technique for medicinal plants due to its ability to retain the medicinal properties of plant material (Muller and Heindl, 2006). In ancient Egypt about 4000 years ago, a scientific distinction was made between sun-dried and shade-dried medicinal plants, based on their quality (Heeger, 1989). In modern medicinal plant drying, factors like production scale, technological advancements, and pharmaceutical quality standards are crucial considerations. Natural drying is suitable for small quantities, but mass production necessitates technical drying methods. To preserve active ingredients, lower drying temperatures are recommended, leading to longer drying durations. Drying constitutes a significant portion (30 to 50%) of the total costs in medicinal plant production (Qaas and Schiele, 2001). In the context of drying medicinal and aromatic plants, identifying factors contributing to high costs is critical. The energy demand for drying, particularly with rising fossil fuel prices, is a significant cost factor, mainly due to the high moisture content of the plant material. For instance, reducing the moisture content from 80% to a storable 11% requires removal of 4 kg of water to get 1 kg of dried material. The specific heat requirement for herbal drugs is twice that of grain drying, leading to considerable heating-oil consumption, which further amplifies with purification losses. Consequently, energy requirements in the drying process are substantial and represent a major expense in medicinal plant processing. The drying performance significantly impacts product quality and value, making managerial decisions crucial for achieving optimal drying conditions. Strengthening the research in this field is much in supporting decision making to realize efficient drying practices.

The post-harvest procedures applied to medicinal and aromatic herbs significantly influence their production chain by affecting the preservation of their active components, ultimately impacting the quality and consumer acceptability of the final product. Among the earliest and most prevalent post-harvest operations for maintaining the quality of medicinal and aromatic plants is the drying process. Typically, traditional drying methods like shade drying and open sun drying are employed. However, these conventional drying approaches exhibit certain limitations concerning the drying of medicinal and aromatic herbs (Mukherjee et al., 2021). Intense solar radiation can have adverse effects on the quality of herbs, leading to colour deterioration and the loss of volatile and bioactive components. Open-air drying methods may also expose the herbs to infestation by insects, birds, rodents, and pests, as well as contamination from dust and dirt. These factors can hinder the achievement of required hygiene standards, product quality, and consumer acceptability. To address the limitations associated with traditional drying, the use of mechanical dryers has been proposed as an alternative for preserving kinds of herbs. Mechanical drying offers faster drying times and greater versatility on a commercial scale, making it a common technique for preservation (Mukherjee et al., 2021). However, number of farmers are still following the conventional types of drying techniques because of its easily available and economic point of concern.

Meanwhile, medicinal and aromatic plants (MAPs) are very well known for its presence of peculiar bioactive compounds. At present scenario and post covid, importance and consumers of plant-based medicine are increasing exponentially despite tremendous development in allopathy science. As per report of World Health Organization (WHO), 88% of the world countries are projected to use herbal medicines in different forms and 80% of human health care medicine is herbal based in the developing countries for primary health. In India, plant-based medicine is recognized under the umbrella systems of medicine such as Ayurveda, Yoga and Naturopathy, Unani, Siddha, and Homeopathy (AYUSH). Therefore, ayurvedic and its allied industries are expanding potentially in worldwide, with annual turnover of Rs. 2,300 crores with reference to Indian herbal base medicinal industry. India and Brazil playing a key role in distribution of medicinal plants in world market. Furthermore, India is rich source of biodiversity and recognized more than 2500 species as medicinal plants flora. In India total exports of herbal raw drugs including extracts was estimated 1,34,500 MT but consumption demand being 1,95,000 MT (Chowti et al., 2018). This kind of gap would unfortunately create a pressure over high-value medicinal plants production line. The quality of produce brings down due to an unsustainable collection/harvesting practice adopted. Beside these, post-harvest handling also plays a vital role in maintaining the quantity of harvested product. Huge amount has loss due to mismanagement and negligence in post-harvest processing technology. As per report of FAO, 1.3 billion metric tonnes of food accounting 33% of the total produce is loss after harvest and if it is continued then the loss would be cross more than 2.0 billion metric tonnes by 2030. In India, post-harvest loss is worth of Rs. 92651 crores and this monetary value is approximately 40 per cent of the total produce in India. Therefore, it is much concern to focus in minimizing the post-harvest losses and need to be strengthen the research in this domain rather only attention in an enhancement of crops production and productivity.

2. Equilibrium moisture content

Agricultural products, especially food grains, experience changes in moisture content due to interactions with the environment. When ambient temperature rises and air humidity decreases, food grains lose moisture through evaporation, leading to drying. The moisture content of grains depends on the temperature and relative humidity of the environment. If the water vapor pressure in grains exceeds that of the air, the water in grains vaporizes and diffuses into the atmosphere. Conversely, if the vapor pressure in grains is lower, the grains absorb moisture from the atmosphere. This property of gaining or losing moisture in response to atmospheric conditions is known as hygroscopicity (Sahay and Singh, 1996). The equilibrium moisture content (EMC) of a hygroscopic material in contact with air is the point at which the material neither gains nor loses moisture. The EMC value is influenced by the material's properties, as well as the temperature and relative humidity of the surrounding air. The equilibrium moisture content of a grain refers to the moisture level achieved when the grain reaches a balance with the surrounding air at specific atmospheric temperature and relative humidity conditions. At EMC, the grain's moisture is in equilibrium with the environment. (Sahay and Singh, 1996).

3. Effect of drying temperature on product quality

The drying process, including factors such as drying method, air velocity, and temperature, significantly impacts the quantity and quality of active constituents found in medicinal and aromatic plants (MAPs). Despite advancements in technology, selecting the appropriate drying temperature remains a critical economic and ecological consideration in the drying of medicinal plants. Discrepancies between recommended values in literature and actual practices underscore the pressing requirement for further research in this area. Nevertheless, it appears that drying air temperatures ranging from 50 to 60°C is feasible for effectively drying a wide variety of MAPs in large quantities (Rocha et al., 2011).

Crop drying is a vital process aimed at enhancing the longevity of agricultural materials while preserving their integrity to the greatest extent possible. This preservation technique entails careful evaluation of the drying methodologies to gauge their effects on crucial aspects such as taste, color, texture, nutritional composition, and other sensory attributes of the food. Striking a harmonious equilibrium between product quality and energy consumption is imperative in the drying procedure, as both factors wield substantial influence on the overall efficiency and effectiveness of the process. Hence, scientific investigation and optimization are essential to achieve the desired outcome in crop drying, ensuring prolonged shelf life and optimal organoleptic characteristics of the materials (Pathare and Roskilly, 2016).

However, there exist conflicting evidences on quality acceptability of hybrid systems dried agricultural products. In the study conducted by Hussein et al., 2016, an investigation was carried out to assess the functional and sensory attributes of dried tomatoes, obtained through three different drying methods: hybrid solar drying, direct solar drying, and open sun drying. These drying techniques were compared to commercially available dried tomatoes from the market. The researchers evaluated several parameters, including wettability, water absorption index, solubility index, bulk density, and organoleptic properties. The results of the study revealed that the tomatoes dried using the hybrid solar dryer exhibited superior performance in terms of the evaluated parameters, suggesting its potential as the most effective method among the three drying techniques. This scientific investigation provides valuable insights into the optimization of drying processes, highlighting the advantages of employing a hybrid solar dryer for improved functional and sensory qualities of the dried product not only in normal crops.

In the study conducted by Pati et al., 2015 the organoleptic assessment of herbal mint revealed favourable attributes concerning colour, door, and taste. Concurrently, the utilization of recovered heat from biomass exhibited promising potential as an efficient thermal energy source for the drying process. Moreover, the examined physiochemical properties, including total ash, acid, insoluble ash, water, and alcohol soluble extractives, were found to comply with the established quality standards set by the pharmaceutical industries. The impact of drying air temperature on essential oil content was investigated by Lemos et al. (2008). Their findings indicated that varying drying temperatures did not significantly affect the essential oil content extracted from the dried plant. Nonetheless, the drying process led to a reduction in the essential oil content compared to the fresh plant. As many MAPs species are used as decoction, colour and odour are an essential quality criterion because it is directly apparent to consumers. For colour measurement, the CIELAB system is frequently applied using lightness L*, chroma C* and hue h as parameters (Pank et al., 1999). Harbourne et al. (2009) conducted an evaluation of the impact of drying at two different temperatures, 30°C and 70°C, on the chemical composition of meadowsweet (*Filipendula ulmaria*) and willow (*Salix alba*). The said two plants are good source of salicylates, which is very similar to aspirin. Drying at 70°C led to reduced flavonoid content and resulted in extracts with a reddish hue, despite the advantage of shorter drying times. The observed decline in flavonoids and simultaneous increase in condensed tannins may be attributed to polymerization processes occurring during high-temperature drying. On the other hand, drying both herbs at 30°C yielded extracts with elevated levels of phenols and active constituents, while maintaining a desirable colour suitable for incorporation into a beverage with potential anti-inflammatory properties. A drying investigation was done in chamomile (*Chamomilla recutita*) with fixed layer at 80°C on the yield and chemical composition of its essential oil and revealed that drying process led to a decrease in both the essential oil content and chemical composition (Borsato et al., 2009).

To enhance drying capacity, it is imperative to select an optimal drying temperature that maximizes efficiency without compromising product quality. The upper temperature limits for drying are primarily determined by the chemical composition of the active constituents present in the MAPs species under consideration. Recommended maximum temperatures are 100°C for glycoside species, 65°C for mucilage species, and 35 to 45°C for essential-oil species, as suggested by Maltry et al., 1975. However, it should be noted that due to the significant heterogeneity among MAPs species, these global guidelines provide only a general indication, and specific drying conditions may need to be tailored to individual plant species to avoid any potential adverse effects on essential oil content and chemical composition of aromatic plants as well as in medicinal plants. Based on that finding of researchers done in different MAPs with an aim to investigate the best drying temperature and its impact on quality are given below Table 1.

Table 1. Effect of drying temperature on quality parameters of MAPs

Sr. No.	Crop	Drying technique	Drying temp.	Quality parameters	References
1.	*Mikania glomerata*	Hot air drying	50°C	Higher essential oil content (0.74 %)	Radunz et al., 2010
2.	*Phyllanthus Amarus*	Vacuum drying	40°C	Retaied maximum natural color and the antioxidant capacity (IC50)	Phong et al., 2013
3.	*Zingiber montanum*	Hot air drying	40°C	Higher curcumin (8.99 mg/g),	Mahayothee et al., 2020
			60°C	Essential oil (9.28 ml/100 g)	
4.	*Cassia angustifolia*	Forced flow type dryer	40°C	Higher Sennoside (2.69%)	Ambrose and Naik (2013)
5.	*Andrographis paniculata*	Hot air oven	65°C	Andrographolide content (4.11%) with higher antibacterial activity	Hathairat et al., 2023
6.	*Stevia rebaudiana*	Infrared drying	55°C	Stevioside (7.88 mg) and Rebaudioside A (8.58 mg)	Huang et al, 2021
7.	*Stevia rebaudiana*	Solar drying	50°C	Stevioside (7.86%)	Amrani et al., 2018
		Oven drying		Rebaudioside A (7.84%)	
8.	*Oscimum sanctunm*	Microwave drying	350 W	Higher retention of protein (3.0 %), carbohydrate (59.6 %), fat (22.2%)	Munde et al., 2018
9.	*Cymbopogon citratus*	Oven drying	40°C	Retained appreciable sensory attributes	Phumudzo et al., 2018
10.	*Adhatoda vasica*	Tray drying	40°C	Maximum alkaloids (15.03 mg/mg), total antioxidant (76%), total phenolics (280.25 mg/g)	Srinivasan and Sivasubramanian, 2014

4. Methods of drying

Drying is a process of moisture removal to reduce water activity in food products, effectively slowing deterioration and maintaining quality. When agricultural products are dried while retaining active nutrients, they can be safely preserved for extended periods. This concentration of dry matter is achieved without compromising the food's tissue, wholesomeness, or physical appearance. Heat and mass transfer are involved in the drying process. Sun drying, a traditional method prevalent in developing countries, is cheap but often leads to uncontrolled drying times, contamination, and low-quality products, potentially causing foodborne illnesses due to the growth of toxic microrganisms. In contrast, modern drying systems offer better quality control but are expensive and energy-intensive (Lamidi et al., 2019). Various techniques can be employed to establish a water-vapor pressure disparity between the product and the surrounding atmosphere during the drying process. The objective of these methods is to either increase the water-vapor pressure of the product or decrease the water-vapor pressure of the air, or achieve both simultaneously. The predominant approaches for augmenting the water-vapor pressure of grains include (1) sun or solar drying (2) conduction drying and (3) infra-red drying. Conversely, to reduce the water-vapor pressure of the surrounding air, the commonly utilized methods encompass (1) heated air drying (2) desiccated air drying and (3) refrigerated air drying (Sahay and Singh, 1996).

Post-harvest procedures, including activities such as collecting plant material from the field, transportation to the farm followed various post-harvest processing activities including drying, are frequently associated with an elevated risk of microbial contamination in MAPs if unscientific procedure is followed. The lack of proper ventilation when storing the harvested material can create conditions conducive to microorganism growth, as a result of increased temperature and humidity triggered by respiratory activity (Bottcher and Gunther, 1995). Interestingly, research conducted on *Hypericum perforatum* (commonly known as St. John's Wort) demonstrated that the microbial count is already considerable even before the harvesting process takes place (Graf et al., 2002). This indicates that the initial contamination might originate from sources other than post-harvest handling, potentially originating from the growing environment or other factors prior to harvesting. These findings emphasize the importance of comprehensive quality control measures throughout the entire MAPs production chain to ensure the safety and efficacy of medicinal products derived from such plants. In the lower layer of the flat-bed dryer, the microbial count exhibited no significant change during the drying process. Conversely, in the conveyor dryer, a notable decrease in bacterial count was observed, attributed to the high variability of Colony Forming Units (CFU). Nevertheless, it can be deduced that the microbial count in the field is already substantial and does not experience an increase during the drying process when employing 'state of the art' technology. Different drying techniques are adopted and suited to dry the samples; accordingly, it maintains their bioactive compounds present in it. In Table 2 showed the different drying techniques used to dried the MAPs with maximum conservation of bioactive compounds.

Table 2. Effect of different drying techniques in quality parameters of MAPs

Sr. No.	Crop	Drying techniques	Quality parameters	References
1.	*Gymnema sylvestre*	CPSD mixed mode solar dryer	Higher Gymnemagenin (29.03 µg/ml), Flavonoid (2.28 mg/g)	Natesh et al., 2021

2.	*Centella asiatica*	Freeze drying	Chlorogenic acid (4.9 mg/g), Rutin (0.98 mg/g), Quercetin (0.28 mg/g), Antioxidant activity (IC50 values of DPPH: 68.6 μg/ml, ABTS: 53.37 μg/ml)	Mohapatra et al., 2022
3.	*Ocimum viride*	Fluidized bed dryer	Reduced moisture content (5.74%) on dry weight basis in 240 minutes with maintaining the best quality of dry leaves	Parmar et al., 2017
		Microwave-drying and oven drying	Retained maximum nutrients during drying	Danso-Boateng, 2013
4.	*Ocimum basilicum*	Shade drying	Higher volatile oil, methyl chavicol and chlorophyll content	Mousa et al., 2008
5.	*Cymbopogan citratus*	Oven drying	Maximum essential oil (3.05%)	Dutta et al., 2014
		Shade drying	Maximum Geranial (33.26%)	
		Oven-drying	Maximum Geraniol (1.81%)	
6.	*Withania somnifera*	Shade drying	Maximum withanolides content (0.049%)	Agrawal et al., 2014
7.	*Curcuma longa*	Solar tunnel dryer	Retain maximum curcumin content	Belay *et al.*, 2021
		Shade-net drying	Maximum retention of curcumin and dry recovery rate	Lokhande *et al.*, 2013
8.	*Artemisia nilagirica*	Shade drying	Highest essential oil (0.61%), β-pinene (22.29%), β-myrcene (0.15%)	Anjum et al., 2015
9.	*Cassia angustifolia*	Shade drying	Maximum sennosides in pods (3.22%) and leaves (2.20%)	Nilofer et al., 2021
10.	*Glycyrrhiza uralensis*	Vacuum freeze drying	Maintain maximum contents of total phenol, total flavonoid, and liquiritin and glycyrrhizic acid.	Zhu et al., 2023

5.1. Type of dryers/drying techniques generally used for drying of agricultural material

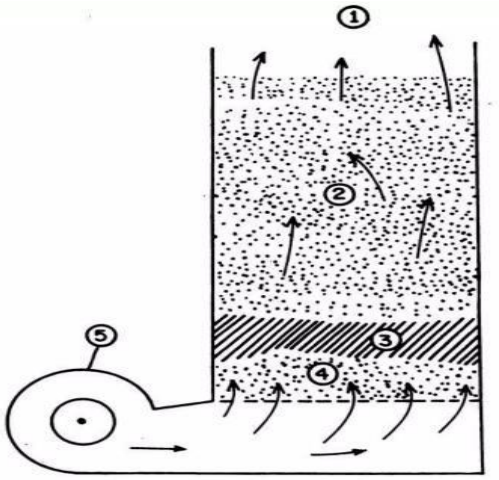
***Sun drying**:* The traditional method of drying crops and grains, which has been practiced since the advent of agriculture, continues to be prevalent in India. A significant portion of harvested crops is left exposed in the field and threshing yard, undergoing sun-drying to achieve the desired moisture reduction. The emission of heat from the sun occurs through electromagnetic waves. The various forms of radiation are distinguished by the wavelengths of these electromagnetic waves.

Shade drying: This kind of drying techniques is generally practiced in those materials which colour is lose when exposed to direct sunlight. The source of heat in shade drying is sunlight but not directly exposed the materials, keep in dry and proper air circulated places. The herbs are dried by heated surrounding air under the low relative humidity. This method reduces biochemical changes occurs during the drying period such as oxidation but such drying techniques has the major disadvantages of a long drying duration (Ghasemi et al., 2013). It was reported that in shade drying oil containing structure of plant like trichomes of Mentha spicata L. leaves are preserved as compared to oven, vacuums and infrared types of drying (Mokhtarikhah et al., 2020).

Mechanical drying: The drying process involves the elimination of moisture from products through simultaneous heat and mass transfer mechanisms. Moisture is typically removed from wet materials by employing a medium, often drying air, to carry away the water vapor. Various products, exhibiting diverse physical and chemical properties, can be effectively dried using heated air. The methods of heat transfer to these products are numerous and diverse, making it challenging to establish a comprehensive classification of all possible drying techniques. Nonetheless, this section outlines some fundamental and frequently employed drying methods.

a. Thin-layer drying: The thin-layer drying process involves the near-complete exposure of plants to heated air, with the product thickness typically limited to a maximum of 15cm. This drying action can be mathematically described using Newton's law (equation 338) by substituting the moisture content for the temperature parameter.

b. Deep bed drying: In deep bed dryers, the drying process occurs within a designated drying zone, where the layer of grains is more than 15cm in thickness. The dryer is designed to allow heated or drying air to enter at a specific point, initiating the drying of the products. As the heated air comes into contact with the bottom layer, a drying zone is formed, and the majority of the drying action takes place in this zone as it moves along the direction of the drying air. To prevent potential over drying, it is recommended that the thickness of the grain layer does not exceed 45cm when using a particular air flow rate at 43°C. The analysis of the deep bed drying method assumes that the deep bed is composed of multiple thin layers showed in Figure 1. In each thin layer, the humidity and temperature of the incoming and outgoing air change over time and through various drying stages. This analytical approach helps determine the duration of the drying process and the quantity of water vapor removed from the products. Additionally, any excess moisture in the dry layer may be further removed until it reaches the equilibrium moisture content.



1. exit air 2. wet grain 3. drying zone 4. dry grain 5. blower

Fig. 1. Deep bed drying techniques [Source: Sahay and Singh, 1996]

c. Flat-bed dryers: Flat-bed dryers have been identified as the most economically advantageous drying system in terms of investment costs. In this method, the harvested material is accumulated to a height of 150cm on a grated floor and subjected to drying through the application of forced air facilitated by ventilators, shown in Fig.2 (Troitzsch, 1961). In the context of decreasing drying duration, conventional approaches involve indirect heating of the drying air through oil or gas-based heating systems. Nevertheless, to prevent excessive drying of lower layers and the development of compaction regions, the bulk material necessitates frequent turning and loosening. Despite the utilization of cranes for the loading and unloading of the dryer, the process remains time-consuming (Maltry et al., 1975). Muller et al. (1989) introduced a unique solar greenhouse dryer that integrates a flat-bed dryer with a cost-effective construction cover made of greenhouse foil. The roof surface of this setup acts as a solar collector, enabling complete substitution of fossil-fuel requirements during the summer months, even under Central-European irradiation levels, as demonstrated by Muller et al. (1994).

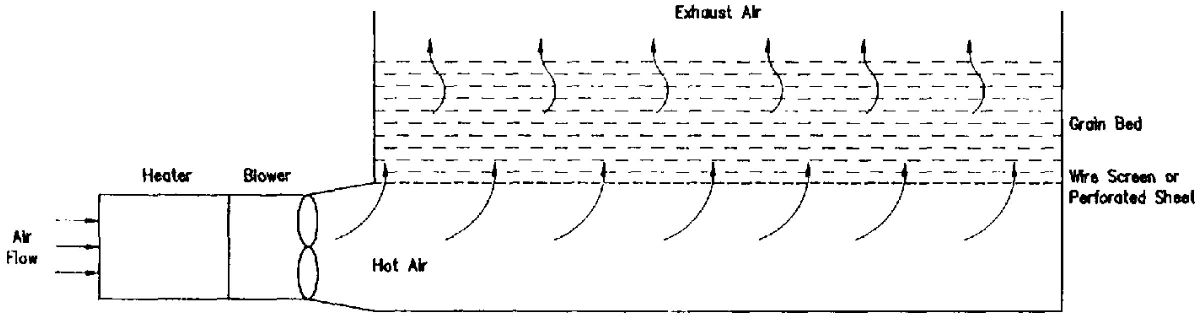


Fig.2. Flat-bed dryers [Source: Vinh and Gavino, 2011]

d. Conveyor dryer: The drying process for roots, flowers, and cut herbs is primarily conducted using conveyor dryers equipped with three to five belts. These dryers facilitate a steady elevation of fresh material through a conveyor belt to the topmost drying belt. The bulk heights for cut roots can reach up to 5cm, while cut herbs may reach up to 20cm. During the turnover of the drying material from a higher belt to a lower belt, the material is effectively loosened and mixed.

To optimize the drying process, the airflow is adjusted individually for each drying belt based on the amount of water evaporation. This entails increasing the airflow from the bottom belt to the top belt. Similarly, the air temperature can be raised due to the cooling effect of evaporation, which prevents overheating in the upper belts. Consequently, belt dryers can operate at higher temperatures compared to batch dryers, increasing their drying capacity without subjecting the drying product to excessive temperature stress. To further enhance drying efficiency, the belt speed is reduced from top to bottom, allowing for better utilization of the drying surface by increasing the bulk height of the drying material. The implementation of mechanical filling, turning, and emptying processes reduces labour requirements when compared to flat-bed dryers. However, continuous operation necessitates constant control and is typically managed through a shift-operation setup.

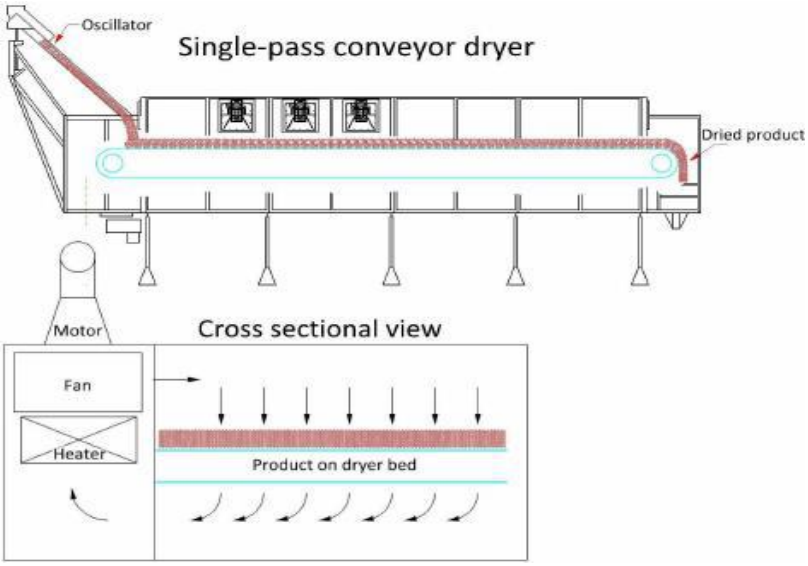


Fig.3. Conveyor dryer [Source: van't-Land, 2012]

e. Freeze drying: This drying method relies on the sublimation of frozen moisture from a wet product positioned within a low-pressure drying chamber. Heat is introduced through radiation or conduction from heated trays, ensuring that the product's temperature remains at or below 0°C. The sublimated moisture is condensed on refrigerated plates within the drying chamber, with no direct contact between these plates and the products.

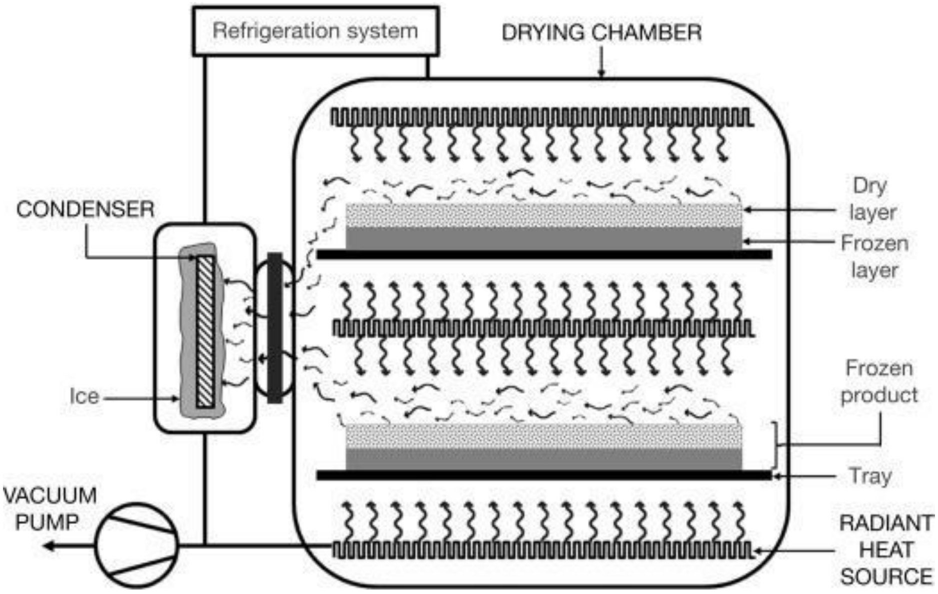


Fig. 4. Freeze drying model [Source: Weblink A]

f. Radiation drying: Heat energy can be introduced to moist substances through electromagnetic waves, specifically in the wavelength range of 0.76 to 400 µm, commonly referred to as infrared radiation. When this radiation interacts with wet materials, it penetrates their surface and induces molecular vibrations, generating a thermal effect. Due to the limited depth of penetration of infrared waves, this drying method is primarily employed for thin materials. The moisture migration and vapor diffusion within the material during this process follow the same principles as observed in convective or contact drying.

g. Fluidised bed drying: In this drying method, the products undergo fluidized drying within a dryer, where drying air is utilized to fluidize the materials by imparting a sufficiently high velocity to suspend them. This fluidization process facilitates enhanced rates of moisture migration. Given that each surface of the product comes into contact with the drying air, a uniform drying of the products is achieved. This technique finds application in the rapid drying of lightweight, high-moisture content materials.

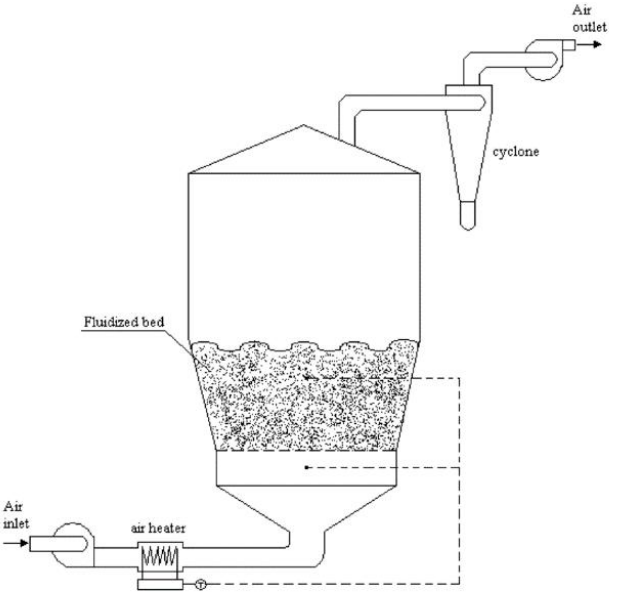


Fig. 5. Fluidised bed drying [Source: Yuzgec et *al.*, 2008]

h. Solar cabinet dryer: The most prevalent variation of this type of dryer is the solar cabinet dryer, illustrated in Fig 6. This dryer's fundamental design comprises an insulated rectangular cabinet with a glass or transparent plastic roof. Perforated drying trays are placed within the cabinet, and holes are present at the base and upper parts of the cabinet. Solar radiation penetrates the roof and is absorbed by the blackened interior surfaces, leading to their heating and subsequently warming the air inside the cabinet. The heated air ascends through natural convection and exits through the upper holes, while fresh air simultaneously enters through the base holes.

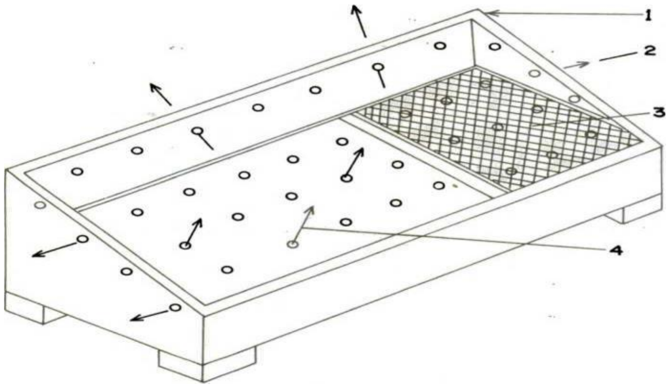


Fig. 6. Solar cabinet dryer [Source: Weblink B]

i. *Continuous microwave drying:* It has been evaluated as an alternate method of conventional drying. Drying rate is very fast and suggests that such drying technique is well suited to large scale industrial drying. Various research finding showed that its innumerable advantages both at laboratory and at industrial production level around the world. This technique is use to dried the various samples including fruits, vegetables, grains, leafy vegetables as well as MAPs. One of the greatest advantages of microwave drying offers against the traditional methods is the rapid drying rate and also recommended that it could be gives more advantages when it use in combine with traditional drying methods. Uniform and rapid generation of heat over the food materials is very quick and this is known as volumetric heating. Heating on water is speedy than the heating on other components present in the food stuffs resulting drying rate is fast. The penetration of electromagnetic waves into food materials is depends on the frequency and nature of the drying materials. Deeper penetration is associated with lower frequency. The range of dielectric frequency absorbed by materials when exposed to electromagnetic waves is directly relation to the characteristic of the drying materials as it contributes to the distribution of dipoles in the materials.

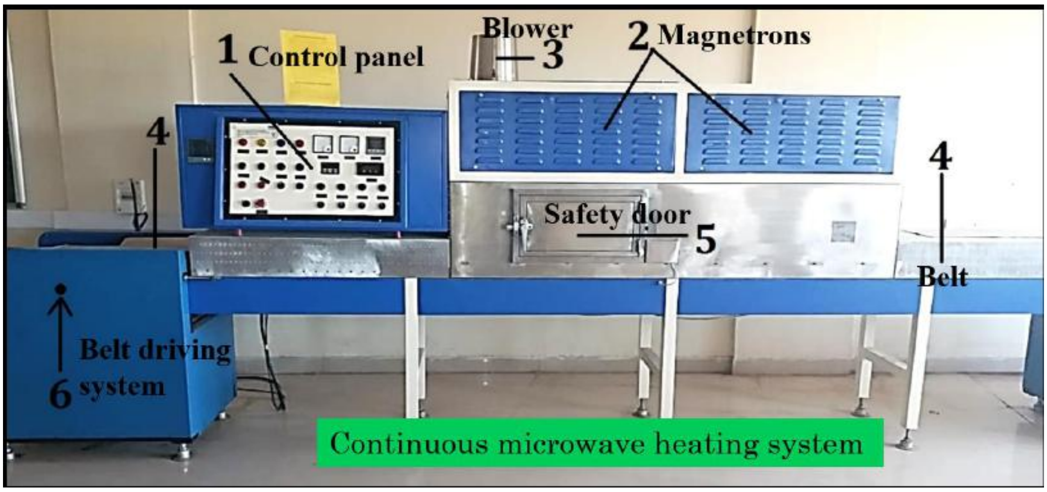


Fig. 7. Continuous microwave drying [Source: AAU, Gujarat, India]

5. Some drying techniques use in MAPs

6.1. *Drying of ashwagandha:* Ashwagandha (*Withania somnifera*) belongs to the family Solanaceae and commonly known as “Indian Winter cherry” or “Indian Ginseng”. It is one of the most prominent medicinal plants used in ayurvedic Rasayana, known as “Sattvic Kapha Rasayana” Herb (Changhadi, 1938). Root is most economic part of the plant, commonly available as a churna and its fine powder can be consumed with water or honey or ghee. Many evidences showed that it improved the reproductive system, brain tonic, overall immunity of the body and also mentioned that it used in the treatment of diseases like arteriosclerosis, premature ageing, arthritis, diabetes, hypertension and malignancy (Singh, 2005). The steroidal lactones (withanolides, withaferins), alkaloids (isopelletierine, anaferine, cuseohygrine, anahygrine, etc.) and saponins are the main bioactive chemical present in ashwagandha (Mishra et al., 2000). However, the industrial growth of medicinal plants is hindered due to an inadequate understanding of the specific post-harvest handling and packaging requirements for a wide range of species and varieties. This shortage of knowledge results in the absence of proper cultivation protocols, commercialization techniques and best practices, leading to limited market opportunities. One key area of concern is the suboptimal management of temperature and humidity during the handling, distribution and marketing processes. As an herbal raw material utilized in the extraction of active principles for numerous commercially significant drugs, *Withania somnifera* (Ashwagandha) is susceptible to deterioration and reduced alkaloid content due to conventional drying methods and improper storage. Consequently, there is a pressing need to standardize the post-harvest drying technique for ashwagandha to enhance the recovery of active principles through improved post-harvest processing.

In the context of ashwagandha root drying, it was observed that shade drying reduced the initial moisture content of approximately 23% to a significant extent in just 14-15 hours, with temperatures ranging from 30-32°C. On the other hand, sun drying proved to be more rapid, removing around 25% of moisture in a shorter period of 6 hours, with temperatures ranging between 33-37°C. Notably, the moisture removal rate was higher in sun drying compared to shade drying. Sun drying, being the conventional approach, is relatively uncomplicated but is influenced by weather conditions, demanding more time and manual labour. Consequently, it remains a widely adopted drying method among cultivators and traders of medicinal herbs. Additionally, cabinet drying demonstrated even faster moisture removal capabilities, where about 49% of moisture could be eliminated within a mere 3.25 hours, with air velocities of 1.4-1.6 m/s. Similarly, with increased air velocities of 1.8-2.0 m/s, cabinet drying removed approximately 52% of moisture in the same time frame. Remarkably, cabinet drying also exhibited higher temperatures, ranging from 52-61°C, surpassing those observed in shade and sun drying processes. The lightness values of the shade, sun, and cabinet dried ashwagandha samples were found to be relatively similar. The Hunter Lab colour values for lightness ranged from 61.42 to 69.19, while the green to blue values varied from 12.27 to 14.05. Moreover, the drying temperature had a notable impact on withanolides content in dried ashwagandha. Shade drying resulted in the maximum withanolides content, while cabinet drying with an air velocity of 1.8 - 2.0 m/s lead to the lowest withanolides content. Combined convective-microwave drying of ashwagandha roots was observed to be more rapid compared to traditional sun drying. The drying data under convective-microwave conditions aligned best with the Page model and highly significant effects of process parameters on rehydration ratio and total alkaloids content were observed.

Dry root

Coarse powder

Fine powder

6.2. Drying of senna: In traditional medicine senna is very famous for its tremendous therapeutic use in laxative and skin diseases. The plant is belonging to the Fabaceae family and botanically known as *Senna alexandrina* Mill. Its contents terpenoids, alkaloids, gylcosides, saponins, steroids, flavonoids, anthraquinones, polyphenol and anthrones etc. (Hennebelle et al., 2009). It has been revealed that various medicinal properties of antimalarial, antidiabetic, antimicrobial, antioxidant, anti-inflammatory, analgesic, antitumor, antinociceptive and anticancer (Ibrahim and Islam, 2014). Sennoside A and sennoside B are the two main glycosides responsible for laxative property whereas sennosides C and D have also been reported presence in plant. Apart from the leaves and pods also contains medicinal value. After harvesting, leaves should be dry in a proper manner to maintain the quality and colour texture. Drying under the sun or shade took long 6-7 days which results in microbial contamination and inferior in quality (Sharma, 2004). Huge amount of heat is generated during drying due to the thick layer which directly impact on colour and sennosides content. Moreover, avoids delay drying, should be proceed for drying just after harvesting as early as possible. However, Nilofer et al., 2021 revealed that 100% shade drying retained maximum sennosides content in leaves (2.20 %) and pods (3.22%) as compared to 50% shade drying and sun drying. It was also highlighted that senna leaves directly exposed to sun light causes loss of quality, colour and contamination of the produce due to the high intensity of UV (Ertekin and Yaldiz, 2004). Further it was mentioned that diurnal variation of temperature in sun drying results in the loss of sennosides content (Pratibha et al., 2018). There are number of research findings showed that mechanical dryers have more advantages than conventional sun and shade drying techniques. The ICAR-CRIDA developed a dryer (CRIDA-Dryer) operated at 50°C showed that higher sennoside and chlorophyll content in leaves (3.6% & 2.5%) and leaves plus stems (3.2% & 2.3%) over other methods like open air and shade drying (Pratibha et al., 2018). Senna leaves dry under the forced flow dryer having the 2 HP motor blower and 6 kW electric heaters chamber operated at temperature 45°C retained significantly maximum sennoside content (2.68%) than 40°C (2.44%) and shade drying (2.20%) (Ambrose and Naik, 2013). This discrepancy is attributed to the formation of heat within the layers during the slow drying process in shade drying, which adversely affects the final product's quality. Improper and delayed drying further leads to undesirable changes in leaf color, turning it black, consequently reducing its market value (Prabu, 2006). The highest sennosides content was observed in leaves (1.28%) and pods (3.21%) dried at 50°C and 40°C in oven dryer respectively and comparatively it was 16.3 and 61.2 % of sennosides content increased over the shade drying (Kumar et al., 2023).


Dry leaves


Dry pods


Powder

6.3. Drying of jivanti: *Leptadenia reticulata* (Retz.) Wight. and Arn. belongs to the family Asclepiadaceae is a climber, commonly known as Jivanti, Swarnjivanti or Dodi. Jivanti specially improves the metabolism, digestive system and enhance the health status of the body (Bawra et al., 2010) and considered to be a rasayana which included among the 10 drugs constituting the ‘Jvaniya gana’ and ‘Vitalizong group’ (Sivaranjan and Indira, 1994). The whole plant contains acetyl alcohol, ß-sitosterol, ß-amyrin, lupanol 3-O diglucoside, leptidine, saponin, flavanoid, luteolin, diosmintin and tannin **(**Sonara *et al.*, 2013**)**. Leaves contain two resins also contain bitter neutral principal, albminous and colouring matter, Ca-oxalate glucose, carbohydrate and tartaric acid **(**Srivastav *et al.*, 1995**)**. Previously reported chemical constitute of *L. reticulata* also includes α amyrin, hentriacontanol (Krishna *et al.*, 1975), ferulic acid, rutin, stigmasterol, a triterpene alcohol simiarenol **(**Subramanium and Lakshmanan, 1977**)** and apigenin (Sastry *et al.*, 1985).

Moreover, pregnane glycosides reticulatin, deniculatin and leptacultin have also been isolated from the aerial parts (Srivastav *et al*., 1995). The research of drying techniques on this crop is very limited and it becomes a new emerging post-harvest processes with aim to conserve the medicinal value and longer storage without deterioration as well. A study was conducted on jivanti using different drying techniques to find out the best suitable drying practices. Among the different drying technique, comparatively higher phytosterols content (campesterol, stigmasterol and β-sitosterol) with its proximate biochemical parameters including macro and micro nutrients was observed in vacuum drying Notably, the leaves of the jivanti plant exhibited the highest nutritional content with better quality than stem and root. (Patel et al., 2022). The shade dried of aerial plant parts of *Leptadenia pyrotechnica* (Forssk.) Decne. revealed that the highest concentration of caffeic acid (3.31%) was observed followed by vanillin (0.18%), vanillic acid (0.06%), ferulic acid (0.05%) and cinnamic acid (0.04%) (Preet and Gupta, 2018).The findings of this study open up opportunities for enhancing the utilization of this herb in food preparations, not only in the field of medicine but also in household food preparation. Moreover, the results can serve as a valuable reference for future research concerning the dietary intake of this herb.

Leaves

Stem

Root

Dry leaves powder

Dry stem powder

Dry root powder

6.4. Drying of Ocimum species: The genus *Ocimum* comprised of more than 150 species and it is very popular for its fragrance and medicinal values in nutraceutical and pharmaceutical industries. In India it is commonly known as ‘Tulsi’ and in Ayurveda, known as “The Incomparable One,” “Mother Medicine of Nature” and “The Queen of Herbs,” and is revered as an “elixir of life” (Singh et al., 2010). The essential oil extracted from various part including leaves, stems, inflorescences, seeds and root contributed significant medicinal properties of tulsi (Khare, 2007). Besides these, it has a good scope in cosmetic and food industries. It’s used in the treatment of cough, cold, bronchitis, stomach disorders, malaria, inflammation and stress and anxiety from an ancient time. The eugenol is the main chemical constituents of *Ocimum sanctum*, scared holy basil growing in India and consist of 0.2-0.3 % essential oil harvested at full bloom stage (90 days crop); the chemical constituents of oil includes the eugenol (53.53 %), methyl eugenol (1.14 %), β-elemene (18.46 %) and β-Caryophyllene (19.26 %) (Maheshwari, 1995). The major bioactive compounds present in essential oil of Indian sweet basil, *Ocimum basilicum* and clove basil (*Ocimum gratissium*) showed 47.99% linalool and 85.82% eugenol, respectively (Amarjeet et al., 2020). Drying of leaves is generally practiced for dry herbage products and even for essential oil extraction process partially shade drying is practiced. *Ocimum sanctum* dried under microwave oven power at 350W exhibited higher carbohydrate (59.6%), protein (3.0%) and ash (15.6%) than the power operated at 70 and 500W. There was no different in moisture content among the microwave oven drying techniques (Munde et al., 2018). The maximum ascorbic acid was found in sun drying (207.45 mg/100g) followed by tray drying at 45°C (206.28 mg/100g) whereas total phenol (174.91 mg/100g) and total anti-oxidant (197.47 mg/100g) was recorded significantly maximum retention in microwave drying in *Ocimum basilicum* (Sharma et al., 2018). It was further suggested that microwave drying dried the basil leaves within the very short period of time (7 min 30 sec) without compromising quality. Beside these, some of the researchers also focus eco-friendly renewable energy drying technique such as low-cost solar dryer which could be used in drying of various MAPs and it could be easily effort by poor farmers. In this line, an experiment was conducted by comparing the shade drying, sun drying and indirect solar drying techniques in sweet basil (Al-Hamdani et al., 2022). Inside the drying chamber the 30-50°C temperature and 21-95% relative humidity was maintained. There was negatively correlated in colour changes with drying duration, however the rate of colour deterioration in solar dryer was less as compared to other drying method. The developed solar dryer showed maximum retention of chlorophyll with water activity of 0.63% and increased total phenol content (1705 mg/100g DM) and antioxidant capacity (0.67 µmol/g DM) in dried product. Microwave-drying and oven drying were found the best drying techniques in *Ocimum viride* for preserving most nutrients compared to the fresh herb, whereas substantial losses in basil leave nutritional values was obtained in ambient-air-drying, hot-air-drying, and sun-drying (Danso-Boateng, 2013). Blanching is a technique use to inactivate the oxidative enzyme activities usually applied prior to drying or storage which can preserve the colour and quality for longer duration. It can fasten the drying process due to the softening of materials.

Blanching of *Ocimum sanctum* leaves at 97°C for 1.5 minutes resulted in minimum shrinkage (66%) with the minimum drying time of 45 min. in hot air dryer as compared to control (shrinkage: 76.25% and drying time: 100 min.). However, maximum rehydration ratio (3.83) was found in the samples of 30-minutes ultrasonic plus blanching pre-treatment (Khamon and Jongyingcharoen, 2019).

Fresh green tulsi

Fresh black tulsi

Fresh sweet basil

Green tulsi powder

Black tulsi powder

Sweet basil powder

6.5. Drying of lemon grass**:** *Cymbopogon citratus* is belongs to the family Poaceae and have strong lemony fragrance due to presence of high content of aldehyde citral, which is occurs in two isomers as citral a (Geranial) and citral b (Neral) (Shahi et al., 2005). This aromatic grass is popularly use in tea because of its lemon flavour and it is a good source of anti-oxidant, anti-microbial and anti-fungal activities (Matasyoh et al., 2011). In folk medicine lemon grass is used for the treatment of nervous and gastrointestinal disorders as well as an analgesic, anti-inflammatory, anti-pyretic, antispasmodic (Lodhi et al., 2014). Literature revealed that drying techniques effects on its essential oil content and its quality (Shanjani et al., 2010). Beside the major content (Citral) of lemon grass essential oil, consists of small amount of geraniol, geranyl acetate, limonene and myrcene (Weiss, 1977). Omidbaigi et al., 2004 showed that amount of essential oil losses during drying was 68%, 10% and 34.3% respectively under sun drying, shade drying and oven drying. Further it was identified that alters in the proportion of chemotypes present in its essential oil. The highest essential oil content (2.34%) on dry weight basis was observed under oven drying at 45°C. Whereas, there was no significant differences in oil content in sunshine (2.10%) and shade drying (2.12). The geranial (31.53%, 39.86% and 37.24%), neral (30.08%, 34.52% and 31.28%) and myrcene (16.61%, 14.49% and 15.42%) were identified as major chemical compounds present in oils extracted from lemongrass leaves dried under sun, shade and oven drying, respectively. (Mohamed Hanaa et al., 2012). However, microwave drying (50W) techniques showed less drying duration (0.9 hour) as compared to sun drying (10 hours), solar drying (8 hours), oven drying at 40°C (15 hours), 50°C (8 hours) and 60°C (6 hours). Significant amount of moisture was reduced in the samples dried under microwave and sun drying (3.3%) (Phumudzo et al., 2018). Meanwhile, an important parameter of dried product is the appearance of colour show the consumer acceptability view (Inchuen et al., 2010) and which is directly proportional to drying temperature and duration. With an increased in temperature there was decrease in value of brightness (L*) as drying of temperature at 40, 50 and 60°C by oven drying had 50.22, 43.74 and 39.62 respectively in dried samples of lemon grass leaves. Moreover, the maximum positive greenness value (a*) was found in microwave drying (1.44) this indicated that negative impact on colour and destroying of colour related compounds during drying; other drying methods (sun, solar and oven) showed negative a* value (Phumudzo et al., 2018). An air velocity is also one of the important factors that effects on reduction of moisture content and quality. Mujaffarr and John (2018) recommended that lemon grass leaves drying at 50°C with an air velocity of 1 m/s gave maximum quality attributes in dried samples and no further improvement was observed with an increase in an air velocity up to 2 m/s.

Fresh lemon grass leaves

Dry lemon grass leaves

Lemon grass leaves powder

References

Agrawal, R., Upadhyay, A. and Preeti, S. N. (2014). Influence of Drying on the quality of Ashwagandha (Withania somnifera), *Journal of Food and Pharmaceutical Sciences*, 2, 63-67.

Al-Hamdani, A., Jayasuriya, H., Pankaj, B. P. and Al-Attabi, Z. (2022). Drying Characteristics and Quality Analysis of Medicinal Herbs Dried by an Indirect Solar Dryer, Foods, 11, 4103.

Ambrose, D. and Naik, R. (2013). Mechanical Drying of Senna leaves (*Cassia angustifolia*). *Current Agriculture Research Journal* 1(1), 65-68.

Amarjeet, S. Th., Amar, A. S., Haresh, L. D., Sushil, K., Jigar, G. M. (2020). Impact evaluation of growth stage and species on morpho-physiological traits and bioactive constituent of essential oil in Ocimum through multi-year experiment, *Industrial Crops & Products,* 158- 113052.

Amrani, H. A., Sudad, K. A. T. and Zeina, M. Ab. Q. (2018). Steviosides composition in stevia rebaudiana bertoni: Effect of drying methods, *Plant Archives,* 18 (2), 2025-2030.

Anjum, N., Singh, A. K. and Tripathi, Y. C. (2015). Impact of drying methods on content and quality ofessential oil from leaves of Artemisia nilagirica (Clarke) Pamp. World Journal of Pharmacy and Pharmaceutical Sciences, 4(9), 1259-1271.

Bawra, B., Dixit, M., Chauhan, N. S., Dixit, V. K. and Saraf, D. K. (2010). *Leptadenia reticulata* a Rasayana Herbs: *A Review. Asian J. Plant Sci*., 9, 314-319.

Belay, H. K., Sirawdink, F. F., Yetenayet, B. T. and Tessema, A. (2021). Effects of Variety and Curing and Drying Methods on Quality Attributes of Turmeric (*Curcuma domestica*) Powder, Food/Feed Science and Technology, 64: e21200697.

Berk, Z. (2018). *Food process engineering and technology*. Academic press. 3rd Edition.

Borsato, A. V., Doni-Filho, L., Rakocevic, M., Côcco, L. C., Paglia, E. C. (2009). Chamomile essential oils extracted from flower heads and recovered water during drying process. *J. Food Process. Preserv*., 33, 500-512.

Bottcher, H. and Gunther, I., (1995). Nachernteverhalten und Nacherntephysiologie von Arznei- und Gewurzpflanzen. *Herba Germanica,* 3, 47-66.

Changhadi, G. S. (1938). Ashwagandharishta -Rastantra Sar Evam Sidhyaprayog Sangrah- Krishna-Gopal Ayurveda Bhawan (Dharmarth Trust) Nagpur, 743-744.

Chowti, S. P., Rudrapur, S. and Naik, B. K. (2018). Production scenario of medicinal and aromatic crops in India. Pharmacogn Phytochem. SP3:274–277

Danso-Boateng, E. (2013). Effect of drying methods on nutrient quality of Basil (Ocimum viride) leaves cultivated in Ghana, *International Food Research Journal* 20(4), 1569-1573.

Debashis, D., Pawan Kumar, A. N., Verma, N. and Gangwar, B. (2014). Qualities of lemongrass (*Cymbopogan citratus*) essential oil at different drying conditions, *International Journal of Agriculture, Environment & Biotechnology*, 7(4): 903-909.

Ertekin, C. and Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of food Engineering*, 63, 349-359.

Graf, C., Schubert, E., Thiele, K., et al., (2002). *Hypericum perforatum* L.: Veranderung des mikrobiologischen Status wahrend Ernte, Transport und Trocknung. *Zeitschrift fur Arznei- und Gewurzpflanzen,* 7 (1), 31-37.

Ghasemi, P. A., Mahdad, E., Craker, L. (2013). Effects of drying methods on qualitative and quantitative properties of essential oil of two basil landraces. *Food Chem*., 141, 2440-2449.

Harbourne, N., Marete, E., Jacquier, J. C., O'riordan, D. (2009). Effect of drying methods on the phenolic constituents of meadowsweet (*Filipendula ulmaria*) and willow (*Salix alba*). *Food Sci. Technol.*, 42, 1468-1473.

Hathairat, C., Chuleeporn, C., Sribud, S. and Rungnapa, B. (2023). Effect of harvesting age and drying condition on andrographolide content, antioxidant capacity, and antibacterial activity in *Andrographis paniculata* (Burm.f.) Nees. *AIMS Agriculture and Food*, 8(1), 137–150.

Heeger, E. F., (1989). *Handbuch des Arznei- und Gewurzpflanzenbaues*. Verlag Harri Deutsch, Frankfurt.

Hussein, J. B., Usman, M. A., Filli, K. B. (2016). Effect of hybrid solar drying method on the functional and sensory properties of tomato. *Am. J. Food Sci. Technol.* 4(5), 141–8.

Hennebelle, T., Weniger, B. Joseph, H. Sahpaz, S. Bailleul, F. (2009). Senna alata, Fitoterapia, 80, 385-393.

Huang, X., Li, W., Wang, Y. and Wan, F. (2021). Drying characteristics and quality of *Stevia rebaudiana* leaves by far-infrared radiation. LWT, 140, 110638.

Ibrahim, M.A. and Islam, M. S. (2014). Anti-diabetic effects of the acetone fraction of Senna singueana stem bark in a type 2 diabetes rat model. *The Journal of Ethnopharmacology*, 153, 392-399.

Inchuen, P., Narkrugsa, W. and Pornchaloempong, P. (2010). Effect of drying methods on chemical composition,colour and antioxidant properties of Thai red curry powder. *Kasetsart Journal*, (Natural Science), 44, 142-151.

Khare, C. P. (2007). Indian Medicinal Plants: An Illustrated Sictionary. Springer Science & Business Media.

Khamon, D. and Jongyingcharoen, J. S. (2019). Application of ultrasonic pretreatment for drying of holy basil (*Ocimum sanctum* L.) leaves, The 12th TSAE International Conference, IOP Conf. Series: Earth and Environmental Science 301, 012045.

Krishna, P. V., Rao, E. V. and Rao, D. V (1975). Crystalline principles from the leaves and twigss of Leptadenia Reticulata. Planta Med., 27(4), 395-400.

Kumar, A. N., Sneha, A., Satya Srinivas, K. V. N. Kiran Babu, G. D., Kotesh Kumar, J., Vijay Kumar, M., Jnanesha, A. C. and Vinutha, K. (2023) Optimisation of harvesting time and drying techniques for higher sennosides in Cassia angustifolia Vahl. by RP-HPLC, *Industrial Crops and Products*, 197, 116591.

Lamidi, R. O., Jiang, L., Pathare, P. B., Wang, Y., & Roskilly, A. P. (2019). Recent advances in sustainable drying of agricultural produce: A review. *Applied energy*, *233*, 367-385.

Lemos, D. R. H., Rocha, R. P., Melo, E. C., Visser, E., Pinheiro, A. L. (2008). Influence of drying air temperature on the essential oil content from *Melaleuca alternifolia* cheel. In: XXXVII Congresso Braz. Agric. Eng., 31, Foz do Iguaçu. Proceedings. Foz do Iguacu: CONBEA, CD Rom.

Lokhande, S. M., Kale, R. V., Sahoo, A. K. and Ranveer, R. C. (2013). Effect of curing and drying methods on recovery, curcumin and essential oil content of different cultivars of turmeric (Curcuma longa L), International Food Research Journal, 20(2): 745-749.

Lodhi, P., Tandan, N., Singh, N., and Kumar, D. (2014) Green tea extract ameliorates ethanol induced liver injuryin Albino rats. *American Journal of Phytomedicine and Clinical Therapeutics,* 2, 603-608.

Matasyoh, J. C. Wagara, I. N. Nakavuma, J. L and Kibural A. M. (2011). Chemical composition of Cymbopogon citratus essential oil and its effect on mycotoxigenic Aspergillus species Afr. *J. Food Sci.*, 5 (3), 138-142

Maltry, W., Potke, E. and Schneider, B. (1975). *Landwirtschaftliche Trocknungstechnik.* 2nd edn. VEB Verlag Technik, Berlin.

Maheshwari, M. L. (1995). Chadha, K.L. and Gupta, R. (Eds.), Quality and Chemistry of Essential oils. *Advances in Horticulture*, 11, 145-195.

Mahayothee, B., Thamsala, T., Khuwijitjaru, P., Janjai, S. (2020). Effect of drying temperature and drying method on drying rate and bioactive compounds in cassumunar ginger (*Zingiber montanum*), *Journal of Applied Research on Medicinal and Aromatic Plants*, 18, 100262.

Mohapatra, P., Ray, A., Jena, S., Nayak, S., Mohanty, S. (2022). Influence of various drying methods on physicochemical characteristics, antioxidant activity, and bioactive compounds in *Centella asiatica* L. leaves: a comparative study. *BioTechnologia* (Pozn). 103(3), 235-247.

Mousa, F. R., Nawal, G. Ghalyand, M. and Attia, A. (2008). Effect of some drying methods on the quality of basil plant (*Ocimum basilicum*, L.), *J. Agric. Sci. Mansoura Univ*., 33 (12), 8667-8675.

Mishra, L. C., Singh, B. B., Dagenais, S. (2000). Scientific basis for the therapeutic use of Withania somnifera. (Ashwagandha): A review. *Alternative Medicine Reviews*, 5, 334-346.

Munde, A. H., Gurjar H. R, Bornare, D. T. Kalyan P. B. and Patil, V. S. (2018). Effect Of Drying On Basil Leave By Using Microwave, *International Journal of Innovative Research and Creative Technology*, 3(6), 38-40.

Mukherjee, A., Nema, A., Sharma, H. P., & Akbari, S. H. (2021). Standardization of drying technique for the production of powder from Shankhpushpi leaves. *The Pharma Innovation Journal*. 10(6), 13-16.

Müller, J. O. A. C. H. I. M., & Heindl, A. (2006). Drying of medicinal plants. *Frontis*, 237-252.

Muller, J., Reisinger, G., Kisgeci, J., et al., (1989). Development of a greenhouse-type solar dryer for medicinal plants and herbs. *Solar and Wind Technology,* 523-530.

Muller, J., Thome, B. and Martinov, M., (1994). Solartrockner fur Arzneipflanzen: eine okonomische Studie. *Drogenreport,* 7 (11), 25-29.

Mohamed Hanaa, A. R., Sallam, Y. I., El-Leithy, A. S. and Safaa, E. A. (2012). Lemongrass (*Cymbopogon citratus*) essential oil as affected by drying methods, *Annals of Agricultural Sciences*, 57(2), 113-116.

Mujaffarr, S. and John, S. (2018). Thin-layer drying behavior of West Indian lemongrass (*Cymbopogan citratus*) leaves. *Food Sci Nutr*., 6(4), 1085–1099.

Mokhtarikhah, G., Ebadi, M. T. and Ayyari, M. (2020). Qualitative changes of spearmint essential oil as affected by drying methods. *Ind. Crops Prod*. 153, 112492.

Natesh, V. B., Nalina, L, Mahendiran, R., Rajamani, K. and Uma, D. (2021). Effect of different drying methods on quality parameters of Gymnema (Gymnema sylvestre R.Br), *The Pharma Innovation Journal,* 10(10), 41-46

Nilofer, Singh, A. K., Kumar, R., Kumar, D., Kaur, P., Singh, A., Shanker, K. and Singh, S. (2021). Optimization of primary post-harvest processing techniques for Cassia angustifolia Vahl., *Journal of Pharmacognosy and Phytochemistry*,10(5), 197-204.

Omidbaigi, R., Sefidkon, F. Kazemi, F. (2004). Influence of drying methods on essential oil content and composition of Roman chamomile. *Flavour and Fragrance Journal*, 19, 196-198.

Pank, F., Schnäckel, W. Hanrieder, D., Langbehn, J. Junghanns, W. Schröder A.and Kühne S.

(1999). Sensorische Qualitat von Majoran (*Origanum majorana* L.). Visuelle Beurteilung und spektrometrische Messung der Farbe und ihr Zusammenhang mit Geruch und Geschmack. *Zeitschrift fur Arznei- und Gewurzpflanzen,* 4 (2), 68-74.

Patel K. (2022). Impact of different drying condition on physio-biochemical, quality and nutrients content of Jivanti [*Leptadenia reticulata* (Retz.) Wight & Arn.]. M. Sc (Agri.) Thesis, Anand Agricultural University, Anand, India.

Pathare, P. B. and Roskilly, A. P. (2016). Quality and energy evaluation in meat cooking. F*ood Eng Rev.*, 8(4), 435–47.

Pati, J. R., Hotta, S. K., Mahanta, P. (2015). Effect of waste heat recovery on drying characteristics of sliced ginger in a natural convection dryer. Proc Eng., 105:145-52.

Prabu, M. J. (2006). Senna variety ideal for rainfed farming in southern districts. The Hindu.

Parmar, M. R., Mahendrasinh, T. K., Jayesh, S. D. and Shyamsundar, S. K. (2017). A comparative study on drying of basil leaves. Agricultural Engineering International: *CIGR Journal*, 19(1), 169-177.

Phumudzo, M., Adewale, O. and Afam, I. O. J. (2018). Effect of Drying on Quality and Sensory Attributes of Lemongrass (*Cymbopogon citratus*) Tea, *Journal of Food Research*, 7(2), 68-76.

Phong, N. T., Duc, L. A. and Khuyen, N. D. (2013). Effects of drying methods and drying temperature on product quality of Phyllanthus Amarus (P. Amarus). *IOP Conference Series: Earth and Environmental Science*, 1155 012013.

Pratibha, G. Srinivas, I. Srinivasa Rao, K., Swathi, K. and Srinivasa Rao, Ch. (2018). Effect of Different Drying Methods on Quality and Economics of Senna (*Cassia angustifolia* Vahl.). *Indian J. Dryland Agric. Res. & Dev.*, 33(2), 50-53.

Preet, R. and Gupta, R. C. (2018). Simultaneous Determination of Phenolic Compounds in *Leptadenia pyrotechnica* (Forssk.) Decne. by Using High-Performance Liquid Chromatography (HPLC-DAD-UV), *Advances in Pharmacological Sciences*, pp: 1-4.

Phumudzo, M., Omolola, A. and Afam I. O. J. (2018). Effect of Drying on Quality and Sensory Attributes of Lemongrass (*Cymbopogon Citratus*) Tea, *Journal of Food Research*; 7(2).

Qaas, F. and Schiele, E. (2001). Einfluss der Energiekosten auf die Rentabilitat im Trocknungsbetrieb. *Zeitschrift fur Arznei- und Gewurzpflanzen,* 6 (3), 144-145.

Radünz, L. L., Melo, E. C., Rocha, R. P., Berbert, P. A. and Gracia, L. M. N. (2010). Study of essential oil from guaco leaves submitted to different drying air temperature. Eng. Agric., 18, 241-247.

Rocha, R. P., Melo, E. C., and Radünz, L. L. (2011). Influence of drying process on the quality of medicinal plants: A review. *Journal of Medicinal Plants Research*, *5*(33), 7076-7084.

Sastry, B. S., Vijaylakshmi, T. and Venkata, R. E., (1985). Chemical constituents of the stem bark of Leptadenia reticulata. Indian Drugs, 22, 611-612.

Singh, N., Hoette, Y. and Miller, R. (2010). Tulsi: The Mother Medicine of Nature. 2nd ed. Lucknow: International Institute of Herbal Medicine. Pp. 28-47.

Sahay, K. M. and Singh, K. K. (1996). *Unit operations of agricultural processing*. Vikas Publishing House Pvt. Ltd..

Sivaranjan, S. and Indira, B. (1994). Ayuvedic Drugs and their Plant Sources, Oxford and IBH Publishing Co. PVt. Ltd. Delhi.

Sonara, B., Saralaya, M. G., Gheewala, N. K. (2013). Phytochemical evaluation of aerial part of *Leptadenia reticulata* (Retz) for polyphenolic compound and free scavenging activity. *Inter. J. of Pharmaceutical Sci.*, (4(1), 3408-3417.

Srivastava, J., Lambert, J. and Vietmeyer, N. (1995). Medicinal plants: an expanding role in development. World Bank technical paper no. 320. Washington, DC: World Bank Agriculture and Forestry Systems.

Subramanium, P. S. and Lakshmanan, A. J. (1977). On the constitutes of Leptadenia Reticulata wight and Arn. Occurrence of simiarenol. *Ind. J. Chem*., 5, 180.

Shanjani, P. S. Mirza, M., Calagari, M. and Adams, R. P. (2010). Effects drying and harvest season on the essential oil composition from foliage and berries of Juniperus excels. *Ind. Crop. Prod. J*., 32, 83-87

Srinivasan, K. and Sivasubramanian, S. (2014). Influence of drying temperature on quality parameters of *Adhatoda vasica* leaves, 3(1),

Singh, N. (2005). Dilemma of Ayurvedic Herbal Medicines / Food Supplements Proc workshop on Essential Medicines, Adverse Drug Reactions and Therapeutic Drug Monitoring. Lucknow: Dept. of Pharmacology & Therapeutics, KGMU, Scientific Convention Centre, pp. 35-41.

Sharma, R., Bhatia S. and Kaur P. (2018). Effect Of Drying Methods On Biochemical Quality Of Basil Leaf, *Agric Res J.,* 55(2), 331-335.

Shahi, A., Kaul, M. Gupta, R. Dutt, P. Chandra, S. Qazi, G. (2005). Determination of essential oil quality index by using energy summation indices in an elite strain of *Cymbopogon citratus* (DC) Stapf, *Flavour Frag. J*., 20,118-121.

Troitzsch, R. (1961). Bau, Betriebsweise und Betriebsergebnisse von Beluftungsanlagen fur Krautdrogen. *Deutsche Agrartechnik,* 11, 174-176.

van't-Land, C. M. (2012). Drying in the Process Industry: John Wiley and Sons Ltd.

Vinh, L. Q. and Gavino, H. F. (2011). Adaptability of Vietnamese reversible airflow flatbed dryer in the Philippines. In *International Workshop on "Agricultural and Bio-systems Engineering (IWABE)", Nong Lam University, Ho Chi Minh City, Vietnam*.

Weiss, E.A. (1997). Essential Oil Crops, CAB International, Wallingford, UK. Pp. 86–103

Weblink A: https://freezedryingsystems.co.in/about/

Weblink B: https://egyankosh.ac.in/bitstream/123456789/12090/1/Unit-12.pdf

Yuzgec, U., Becerikli, Y. and Turker, M. (2008). Dynamic neural-network-based model-predictive control of an industrial baker's yeast drying process. *IEEE Transactions on Neural Networks*, 19(7), 1231-1242.

Zhu, L., Li, M., Yang, W., Zhang, J., Yang, X., Zhang, Q., Wang, H. (2023). Effects of Different Drying Methods on Drying Characteristics and Quality of *Glycyrrhiza uralensis* (Licorice). *Foods*. 12(8), 1652.