EIP-AGRI Focus Group
Plant-based medicinal and cosmetic products

MINI PAPER 7. Postharvest Handling and Drying of Medicinal & Aromatic Plants

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1. Introduction

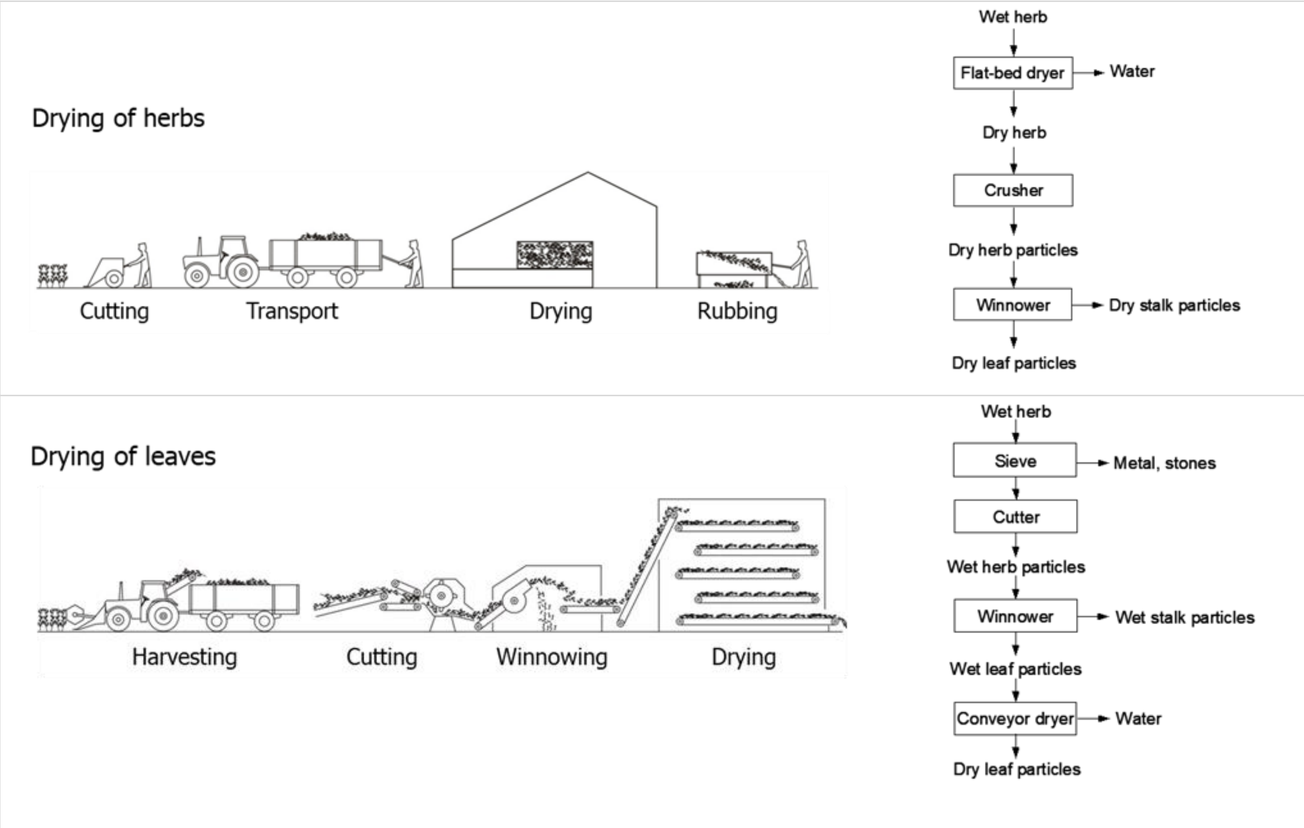
The value chain of medicinal and aromatic plants (MAPs) encompasses all processing steps to produce plant-based medicinal and cosmetic products. The process steps of raw material sourcing, postharvest handling and drying are performed by farmers/local collectors and processors individually or in a cooperative and therefore constitute a special interest of this Focus Group. Also, the vast majority of the trade worldwide is based on dried herbal drugs. **On-farm drying is a key process during postharvest handling of medicinal plants and a fundamental step for the production of herbal medicinal products**. Different dryer types are used for MAPs e.g. typical grain dryers for seeds, tray dryers for flowers, fruits and roots. Drying of medicinal plants involves low drying temperatures in order to protect the heat sensitive active ingredients. Energy requirement of medicinal plant drying represents a significant cost factor (e.g., twofold in comparison with grain drying) due to the high moisture content of the individual plant parts to be dried.

The purpose of this mini paper is to give an insight to postharvest processing and especially drying of medicinal plants, identify urgent research needs from practice and propose noteworthy innovative ideas.

2. State of the art

Postharvest handling

On-farm drying of herbs is commonly performed in flat-bed dryers or conveyor-belt dryers following low or high mechanised processing lines, respectively[1] (Figure 1). The saturation deficit of the drying air is a decisive factor for bulk drying of medicinal and aromatic plants in practice.



[1] Heindl A & Müller J, 2010. Technische Trocknung. In: Hoppe B (Ed.), Handbuch des Arznei- und Gewürzpflanzenbaus – Band 2: Grundlagen des Arznei-und Gewürzpflanzenbaus, Teil II (pp. 239-294). Verein für Arznei- und Gewürzpflanzen SALUPLANTA e.V. Bernburg, Germany.

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Figure 1. Medicinal plant postharvest processing chains: basic vs. complex (Source: Heindl & Müller, 2010[1])

Low-mechanised processing line: Whole plants can be dried by forced air in modular flat-bed dryers. The drying air passes through material bulks with a height of 50 cm or more. The bulk, representing uncut harvested plant material should be turned and mixed several times during drying to avoid uneven moisture distribution and over-drying of the lower layers. The drying air is usually heated indirectly by oil or gas burners. After drying the drug is crushed to separate the worthless stalks from the leaves. This process is characterised by a prolonged drying time and considerable energy losses. As a specialised construction, a flat-bed dryer can be integrated into a solar greenhouse dryer. Drying in practice of some herbs in flat-bed dryers is shown in Figure 2.

Figure 2. Flat-bed drying of herbs (Source: Left to right- Argyropoulos/UCD, Ziegler/ATB, Planungsgruppe Fölsche)

High-mechanised processing line: For drying of herbs in multi-belt conveyor dryers, the herb is cut to size of 5 cm and the leaf particles are separated from the stalks by winnowing. The bulk leafy material of 10 cm in height is continuously transported by a conveyor belt into the dryer. The dryer is divided into different temperature zones. Higher air flow is provided in the upper belts, which is proportional to the amount of evaporated water. The highly mechanized processing line of medicinal and aromatic plants is shown exemplarily for lemon balm in Figure 3. Oil or gas heating systems are commonly used to heat the drying air. In addition, the waste heat from a combined heat and power unit of a biogas plant can be supplied to reduce the fossil-fuel requirement[2]. Alternatively, installation of a wood chip heating system or solar thermal collectors would support the conventional burner. Drying of leaves reduces the drying time and the energy costs substantially, however a higher investment is required in comparison with flat-bed drying.

Practical information on drying of medicinal and aromatic plants:

Handbook of Medicinal and Aromatic Plant Cultivation – Volume 2**:** Technical drying of MAPs (Handbuch des Arznei- und Gewürzpflanzenbaus)
https://www.saluplanta.de/handbuch-band-1-bis-5.html

The European Herb Growers Association (EUROPAM)[3] position on drying factors for medicinal and aromatic plants (MAPs). Journal of Applied Research on Medicinal and Aromatic Plants[4], 11, 1-2
https://www.sciencedirect.com/science/article/pii/S2214786118301943

Guidelines for drying of medicinal and aromatic plants in practice

[2] Böhner M, Heindl A, Müller J, 2012. Reduktion des fossilen Energieverbrauchs eines Bandtrockners für Arznei- und Gewürzpflanzen durch die Abwärmenutzung eines Biogasblockheizkraftwerkes. Zeitschrift für Arznei- und Gewürzpflanzen, 17, 115-121.
[3] http://www.europam.net/
[4] https://www.journals.elsevier.com/journal-of-applied-research-on-medicinal-and-aromatic-plants/

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(Erstellung eines Leitfadens für die Trocknung von Arznei- und Gewürzpflanzen)
https://www.fnr.de/index.php?id=11150&fkz=22015612

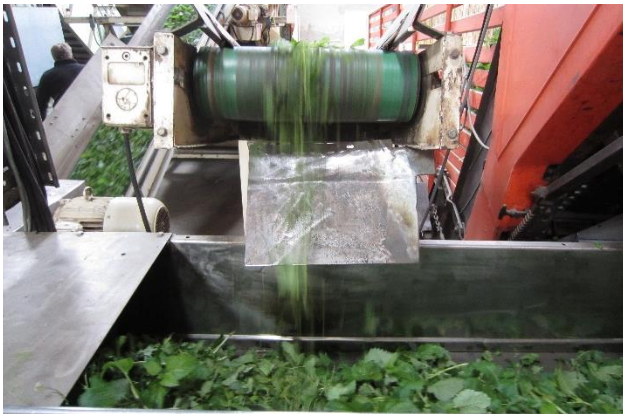

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Figure 3. Highly mechanised processing line of medicinal and aromatic plants: Harvesting, transportation, cutting, winnowing, drying in a conveyor-belt dryer and on-farm storage of herbs (Source: Argyropoulos, 2015[5])

3. Research needs from practice

Drying parameters

The drying behaviour of medicinal and aromatic plants is mainly affected by the conditions of drying air such as temperature, relative humidity and velocity. Low-temperature drying results in a long drying process, increasing at the same time the energy requirement and the production costs. On the other hand, herbs subjected to higher drying temperatures are characterised by poor quality[6]. As a consequence, the dried drugs are often rejected by end-users or wholesale buyers. The choice of the optimal drying conditions is, therefore, a central economic and ecological criterion. To achieve high drying capacity, saving at the same time energy, a maximum allowable temperature should be applied but with a minimum deterioration in quality[7]. Investigations on lemon balm and examples of multi-source data that have been collected to help farmers with decision making in every day on-farm drying operations are presented in Figure 4.

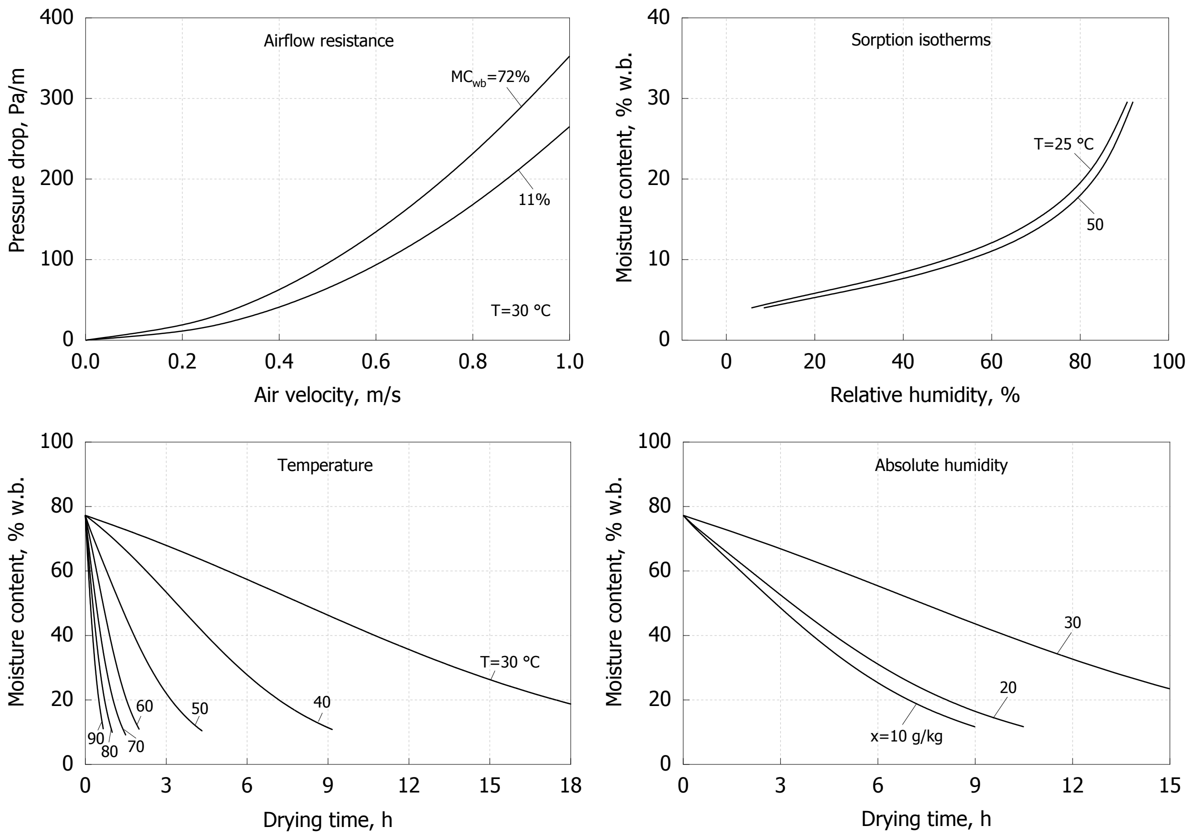

Figure 4. Multi-source drying-related data of lemon balm (*Melissa officinalis* L.)[8]

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[5] Argyropoulos D, 2015. Modelling sorption behaviour and process kinetics of lemon balm (*Melissa officinalis* L.) for optimization of drying with regard to quality and energy requirement. Shaker Verlag GmbH, Germany.

[6] Argyropoulos D & Müller J, 2014. Changes of essential oil content and composition during convective drying of lemon balm (*Melissa officinalis* L.). Industrial Crops and Products, 52, 118-124.

[7] Müller J, 2007. Convective drying of medicinal, aromatic and spice plants: A review. Stewart Postharvest Review, 3, 1-6.

[8] Argyropoulos D, Müller J, 2019. Decision support for drying of medicinal plants through multi-source data integration. In: 7th European Drying Conference, July 10-12, Turin, Italy, pp. 78-79.

Quality of herbal drugs is of primary importance to the end-use industries, however, general recommendations in terms of optimum drying temperature can not be given due to the high heterogeneity of the active compounds, their composition and their location among medicinal plant species. Experiments with a range of air conditions in a high precision laboratory dryer are required in order to investigate relevant quality changes of herbs during convective drying via mathematical modelling[5].
The effect of drying parameters on quality has to be studied for each medicinal plant species separately taking into account the physical properties of the herb to be dried, its active ingredients and the thermophysical properties of air. The minimum quality requirements and recommended acceptance criteria for microbiological quality of dried herbal drugs are postulated in the European Pharmacopoeia (Ph. Eur.)[9], Europe's legal and scientific benchmark for pharmacopoeia standards which contribute to delivering high quality medicines in Europe and beyond.

In addition, wholesale buyers and the pharmaceutical industry set their own specifications in terms of essential oil content and composition. Colour of MAPs, in turn, is considered as a primary quality criterion to the consumers, who prefer leaves with a natural appearance. Colour changes of dried herbs may also imply quality deterioration during postharvest processing via undesired chemical reactions.

Various state-of-the-art analytical techniques e.g. CIELAB colorimetry, spectrophotometry, high performance liquid chromatography, scanning electron microscopy and gas chromatography are also used to assess colour, active ingredients e.g. rosmarinic acid in case of lemon balm, microstructure, essential oil content and composition. Innovative technologies (e.g. hyperspectral imaging, near-infrared spectroscopy and infrared thermography) and optical sensing with artificial intelligence can be used for quality and process monitoring[10].

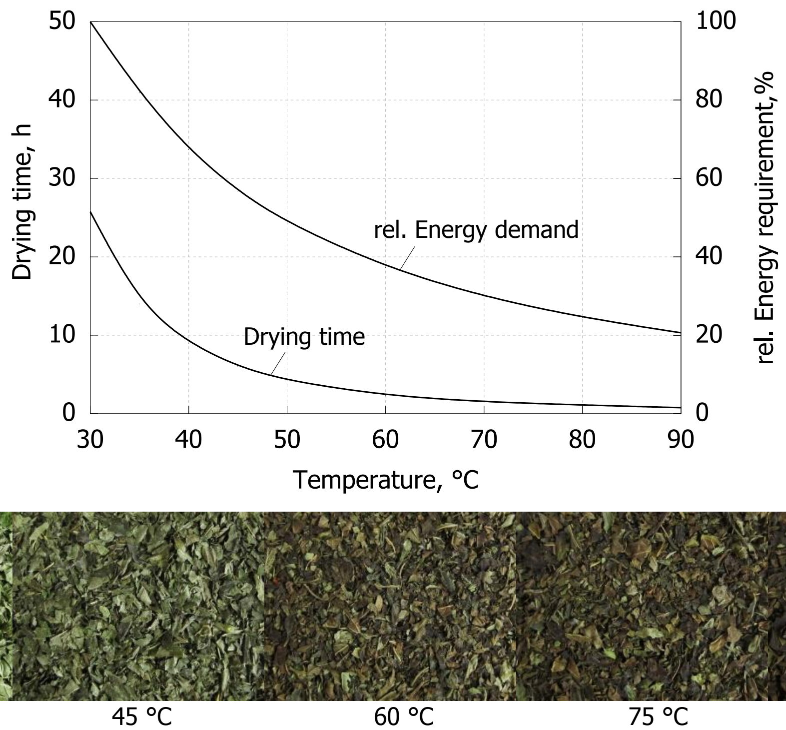

Figure 5. Drying time and rel. energy requirement vs. temperature (and colour) of lemon balm (*Melissa officinalis* L.)[11]

[9] https://www.edqm.eu/en/european-pharmacopoeia-ph-eur-9th-edition
[10] Argyropoulos D, Nagle M, Romano G, Müller J, 2017. Multi-sensor approach for monitoring rosmarinic acid degradation during drying of lemon balm. In: 11th European Conference on Precision Agriculture (ECPA). Edinburgh, Scotland, July 16-20.
[11] Argyropoulos D & Müller J, 2014. Kinetics of change in colour and rosmarinic acid equivalents during convective drying of lemon balm (*Melissa officinalis* L.). Journal of Applied Research on Medicinal and Aromatic Plants, 1, 15-22.

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Research results showed that optimal drying temperature for lemon balm is 40 °C, because moderate quality degradation was observed. Compared to drying at 30 °C, drying time was reduced by 65% and consequently energy demand was remarkably reduced (Figure 5). The choice of drying temperature still remains a decision of the end-user, implying a trade-off between energy consumption and product quality. Apart from convective drying, alternative drying techniques (e.g. microwave drying, vacuum drying and freeze drying) can be used to enhance product quality of medicinal plants, reducing at the same time the drying time and energy consumption[12]. For efficiency reasons, modern drying technologies are often applied in combination with conventional hot-air.

Systematic research on drying parameters / drying technologies and their effects on overall quality and safety of specific medicinal plants species is still scarce.

Moisture sorption isotherms

On-farm storage is very important to both farmers and buyers. After drying, the bulk of the dried plant material is filled in sacks and stored at ambient indoor conditions in aerated storage facilities. The demand for a continuous and uniform supply of dried herbal drugs requires advanced traceability tools and short supply routes to the end-use industries.

On-farm storage is critical as micro-organisms i.e., moulds, yeasts and bacteria increasingly grow at water activity, $a_w > 0.7$, while enzymatic activity is also promoted by high values of water activity. A general threshold of $a_w \leq 0.6$ is recommended to prevent quality degradation by microbial or enzymatic activity of medicinal plants during storage (Figure 6). Electric hygrometer sensors (resistance- or capacitance-type) and chilled mirror dew point hygrometers can be used in practice for the indirect measurement of water activity.

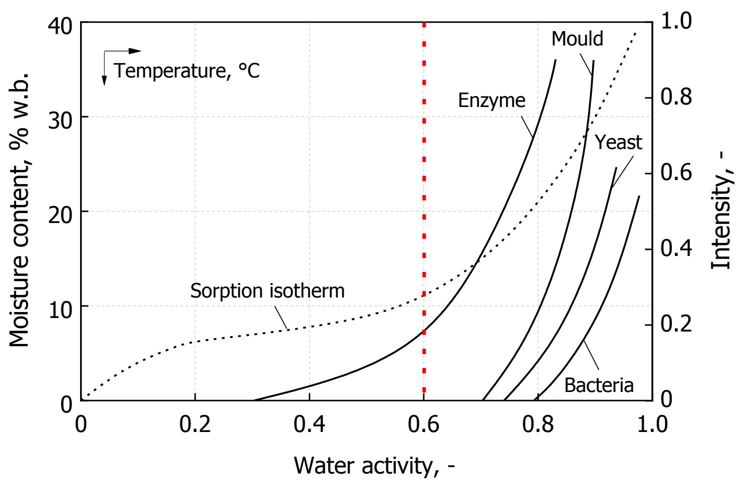

Figure 6. Moisture content of a medicinal plant material and intensity of activity of bacteria, yeast, mould and enzymes vs. water activity[13]

[12] Argyropoulos D. and Müller J., 2014. Effect of convective-, vacuum- and freeze drying on sorption behaviour and bioactive compounds of lemon balm (*Melissa officinalis* L.). Journal of Applied Research on Medicinal and Aromatic Plants, 1, 59-69.
[13] Heiss R, Eichner K, 1990. Haltbarmachen von Lebensmitteln: chemische, physikalische und mikrobiologische Grundlagen der Verfahren, Springer-Verlag, Berlin, Germany.

To decide on suitable final moisture content for specific temperature during processing, storage and transportation, knowledge of the equilibrium relationship between the moisture content in the plant material and the relative humidity of the surrounding air is necessary.

This information in practice can be obtained by the moisture sorption isotherm, which represents a characteristic property of the medicinal plant species[14].
In addition, through analysis of the sorption data, the minimum amount of energy required for drying under certain conditions can be estimated. For drying optimization, the sorption isotherm of each individual plant species should always be established at several temperatures. Due to the lack of moisture sorption isotherms for specific medicinal plant species, there is an urgent need for research in this field.

Very few research projects dealing with drying practices and technologies for medicinal and aromatic plants have been recently carried out or are currently ongoing across Europe. As drying of medicinal plants is especially energy intensive, this forms a special research interest. Emphasis is laid on the choice of drying temperature, because of its strong influence on economic parameters (drying capacity, energy requirement and drug quality).

Therefore, research must be focused on the following areas:

- Database on optimal drying related data of medicinal plant species across Europe;
- Air flow resistance measurements of model medicinal plant species (e.g. seeds, flowers, leaves, roots);
- Moisture sorption isotherms for various medicinal plant species;
- Experiments with a range of drying conditions both in laboratory and in practice;
- Energy use efficiency in the practical drying of medicinal and aromatic plants;
- Primary energy demand and energy costs of flat-bed drying and conveyor belt drying;
- Drying parameters and their effects on active ingredients of specific medicinal plant species;
- Model based investigation of drying process and quality changes;
- Real-time process monitoring by means of a network of sensors;
- Spectral imaging for the non-destructive assessment of active ingredients;
- Mechanisation and automation technologies in postharvest processing;
- Decision support system based on multi-source data integration;
- Reduction of Polycyclic Aromatic Hydrocarbons (PAHs) in herbal drugs during drying;
- Innovative drying technologies and their effects on drug quality, safety and energy requirement;
- Practical tool for prediction of quality and microbiological safety during storage.

The laboratory experiments must be validated in drying practice followed by on-farm demonstration and training activities for practitioners.

Demonstration Project Medicinal Plants – KAMEL (Demonstrationsprojekt Arzneipflanzen) funded by BMEL - Förderprogramm Nachwachsende Rohstoffe (FNR)
https://pflanzen.fnr.de/projekte/arzneipflanzen/demonstrationsprojekt-arzneipflanzen-kamel/
The aim of the project was to demonstrate the performance, efficiency and usability of the breeding, cultivation, harvest and postharvest technologies across three medicinal plant species, i.e. chamomile flowers, lemon balm leaves and valerian roots in a real-scale situation with the active involvement of practitioners from the MAP sector.

[14] Argyropoulos D, Alex R, Kohler R, Müller J, 2012. Moisture sorption isotherms and isosteric heat of sorption of leaves and stems of lemon balm (*Melissa officinalis* L.) established by dynamic vapour sorption. LWT - Food Science and Technology, 47, 324-331.

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4. Innovative ideas

Drying is the most common technique for the preservation of medicinal and aromatic plants, however, due to high investment and energy costs, drying also represents a large expense. Driven by the increased price of fossil fuels, energy demand of drying represents a significant cost factor. Thus, a potential area for innovative projects include developing energy-smart and environmentally friendly drying systems adapted to farmer needs, and best practices for collecting and delivering hybrid and/or solar assisted dryers.

Innotech drying centre

The Innotech drying centre (Figure 7) offers an opportunity to reduce the high actual energy cost of MAP drying significantly while maintaining product quality. The overflow mode of air as well as the pre-set recirculation air mode not only leads to a reduction of the specific energy requirement, but also guarantees uniform drying in the entire drying container. A proportion of the exhaust air from the container is recirculated to mix with the fresh-air intake. The fan develops enough pressure to overcome the air flow resistance and move air through the plant material. Heat is transferred to the drying air by means of an air-water heat exchanger which is installed in the upper level of the drying container. The drying air can be heated by gas, fossil fuel, wood, solar energy or even the waste heat of a district heating central plant. Up to 10 trolleys with 30 trays each can be loaded into the drying container.

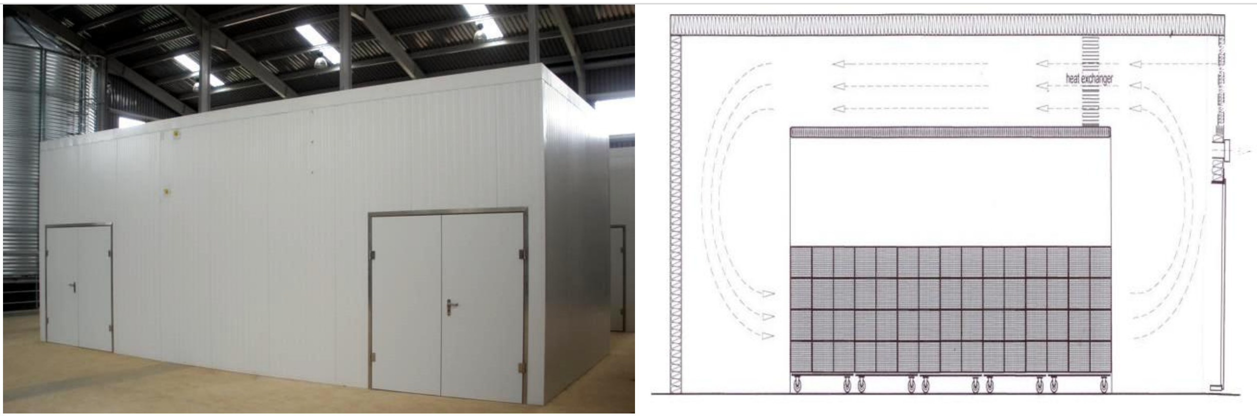

Figure 7. Innotech Drying Container (Source: https://www.innotech-ing.de/en/dryingchamber.html)

Solar greenhouse dryer

A special construction is presented of a solar greenhouse dryer into which a flat-bed dryer was integrated with a cost-effective construction cover of greenhouse foil (Figure 8). The roof surface serves as a solar collector during the summer months when the fossil-fuel requirement can be substituted completely, even with Central-European irradiation levels.

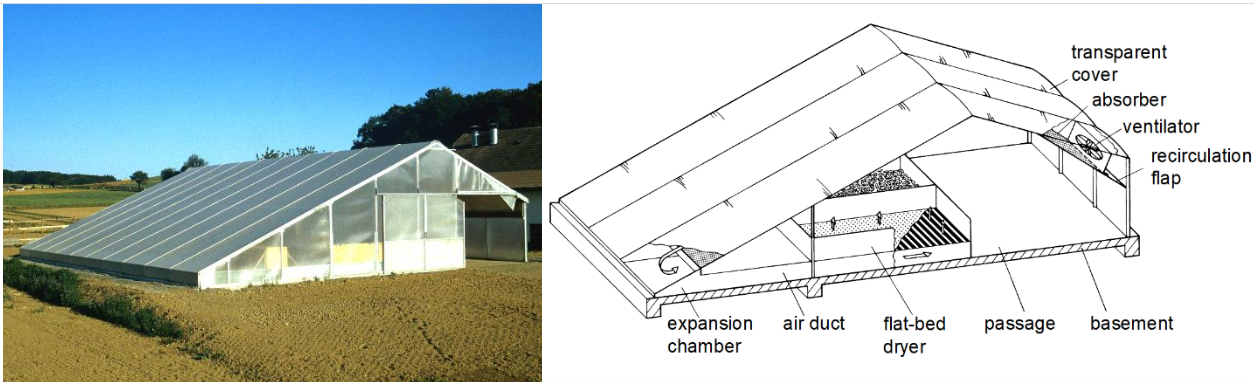

Figure 8. Solar greenhouse dryer, in which a flat-bed dryer has been integrated (Source: Müller, 1992[15])

Solar tunnel dryer type "Hohenheim"

The solar tunnel dryer type "Hohenheim" (Figure 9) unites simple construction, use of renewable energy and easy handling, developed by the Institute for Agricultural Engineering at the University of Hohenheim and Innotech Ingenieursgesellschaft mbH. Solar tunnel dryers are in commercial operation in more than 100 countries all over the world, particularly apt for production of high quality herbs and other crops. Also an increasing number of organic farmers use the ecological advantages of the solar tunnel dryer for the production of their high-value crops.

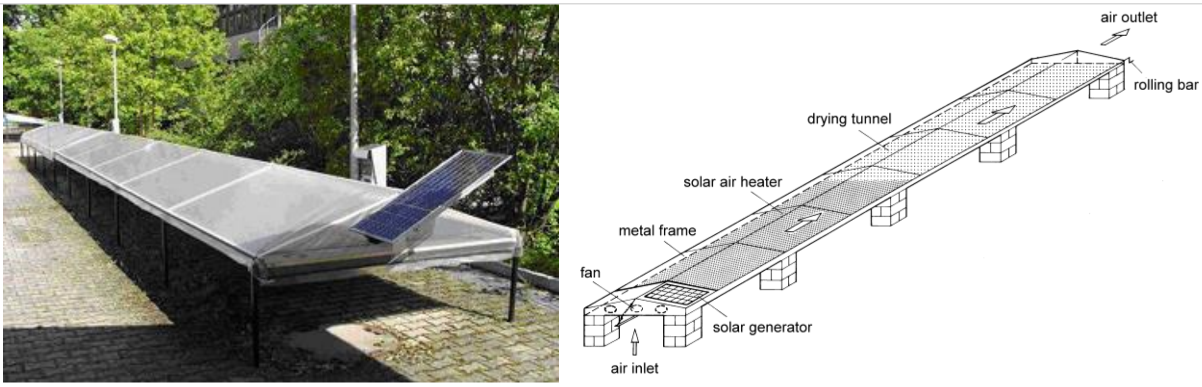

Figure 9. Solar tunnel dryer type Hohenheim (Source: https://www.innotech-ing.de/en/TT.html)

GrainPro Solar Bubble Dryer

Innovative Crop Drying Technology, Solar Bubble Dryer (SBD) is jointly developed by the International Rice Research Institute (IRRI), Philippines, GrainPro which is a leading postharvest solution providing company and the University of Hohenheim in Stuttgart, Germany. The Solar Bubble Dryer is a low-cost, portable drying technology that aims to provide a simple and flexible alternative to sun-drying, while protecting from spillage, animals, weather and vehicles running over the grains (Figure 10). The Solar Bubble Dryer uses energy from the sun in two ways: Firstly, the drying tunnel serves as a solar collector, secondly, it is equipped with a photovoltaic system consisting of a solar panel, a deep cycle rechargeable battery and a controller to generate electricity that drives a small blower to move air through the drying tunnel, inflate the tunnel and remove the water evaporated from the plant material placed inside the tunnel.

[15] Müller J, 1992b. Trocknung von Arzneipflanzen mit Solarenergie. Verlag Eugen Ulmer, Stuttgart, Germany.

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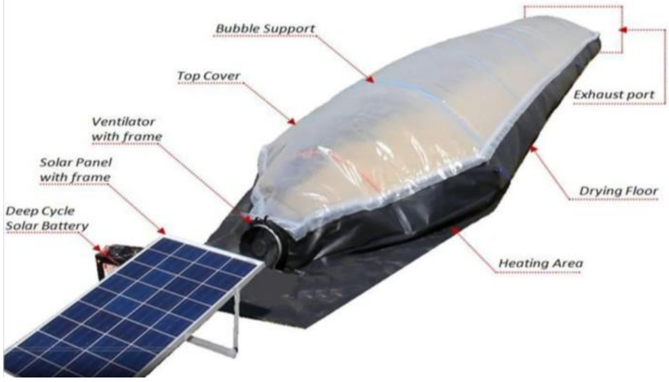

Figure 10. GrainPro Solar Bubble Dryer™ (Source: https://grainpro.com/grainpro-bubble-dryer/)

Black block hybrid solar drying system

Black Block® is a modular, hybrid solar drying system using both solar and electric energy, designed to dry herbs and other crops in recycled black containers, insulated with a new wall and covered by polycarbonate sheets (Figure 11). The hybrid solar dryer consists of the solar collector, where the air used in the drying process is heated, and the drying container, where the material to be dried is placed in sacks, trays or trolleys. Automatic control of drying conditions in the container is achieved by real-time acquisition and analysis of temperature and humidity data through a network of sensors and artificial intelligence. Air is heated throughout the day in the solar collector, however, in conditions of low radiation intensity (a cloudy sky or night time operation), the dryer activates the auxiliary heating system. Practical experience highlights significant savings in energy costs.

Figure 11. Black block – hybrid solar drying system (Source: https://blackblock.eu/en/homepage-en)

5. Ideas for new Operational Groups

The Table below presents the Operational Groups by theme and provides a short description of the proposed solutions.

Table 1 Potential Operational Groups in the MAP postharvest processing sector

Theme	Description
Data assimilation from soil-plant-climate and	Use of sensors to monitor environmental data related to the

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postharvest processing sensor network	air-plant-soil nexus. Integration of multi-source data (e.g. weather, soil humidity, plant growth) collected on farm.
Automated platform for technical drying and postharvest management in the MAP sector	The aim is to develop an integrative computer tool, aimed at the MAP production and processing sectors as well as companies supplying technology for drying control.
Valorisation of by-products and waste from processing into novel value-added products	The aim is to manage the by-products and waste generated in large volume during postharvest handling and on-farm distillation through profitable valorisation technologies.
Cooperative society of growers, agricultural businesses and technology providers	The aim is to create promising organisational concepts to link up the herb farms, raise their profitability through shared processing facilities, establishment of machinery rings and optimise harvesting, drying, storage and transportation.
Portable, energy-smart dryers for MAPs	The aim is to construct portable drying equipment adapted to grower needs and plant material specifications.
On-farm distillation units	The aim is to demonstrate the implementation of innovative essential oil distillation units and process optimisation in terms of yield and energy performance.
On-farm extraction of active ingredients and development of herbal medicinal products	The aim is to optimise the extraction of active compounds from MAPs taking into account process specific variables such as solvent to be used, dried drug/solvent ratio, number of extractions in sequence, extraction temperature and time.

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The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on: http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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