Stepwise drying of medicinal plants as alternative to reduce time and energy processing

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Abstract. The objective of drying medicinal plants is to extend the shelf life and conserving the fresh characteristics. This is achieved by reducing the water activity (aw) of the product to a value which will inhibit the growth and development of pathogenic and spoilage microorganisms, significantly reducing enzyme activity and the rate at which undesirable chemical reactions occur. The technical drying process requires an enormous amount of thermal and electrical energy. An improvement in the quality of the product to be dried and at the same time a decrease in the drying cost and time are achieved through the utilization of a controlled conventional drying method, which is based on a good utilization of the renewable energy or looking for other alternatives which achieve lower processing times without sacrificing the final product quality. In this work the method of stepwise drying of medicinal plants is presented as an alternative to the conventional drying that uses a constant temperature during the whole process. The objective of stepwise drying is the decrease of drying time and reduction in energy consumption. In this process, apart from observing the effects on decreases the effective drying process time and energy, the influence of the different combinations of drying phases on several characteristics of the product are considered. The tests were carried out with Melissa officinalis L. variety citronella, sowed in greenhouse. For the stepwise drying process different combinations of initial and final temperature, 40/50°C, are evaluated, with different transition points associated to different moisture contents (20, 30, 40% and 50%) of the product during the process. Final quality of dried foods is another important issue in food drying. Drying process has effect in quality attributes drying products. This study was determining the color changes and essential oil loses by reference the measurement of the color and essential oil content of the fresh product was used. Drying curves were obtained to observe the dynamics of the process for different combinations of temperature and points of change, corresponding to different conditions of moisture content of the product.

1. Introduction
Lemon Balm (Melissa officinalis L.) is important due to its medicinal properties and its use as tea. Its essential oil is required mainly in the pharmaceutical, food and cosmetic industries. The properties of the plant extract include sedative, relaxing, antibacterial, antiviral, and antispasmodic effects [1,2].
The main components of the essential oil are citral, citronellal and linalool. By means of gas chromatography studies of the essential oil, 70 components are known [3,4,5]. Lemon Balm has low essential oil content (among 0.05 and 0.12 % vol.) [3].

Drying food, agricultural, medicinal plants and biological active materials is an important operation in agricultural, food, [6] and pharmaceutical industries to improve the preservation properties of the product, to reduce transportation costs in order to make the utilization of the products easier and efficient. [7,8]. The reduction of water content and the increase of the temperature of the solid during drying can lead to destruction or decrease of product quality [10]. Structural and physical modifications can take place, as for example the coloring, crust formation, decrease of organoleptic quality, inactivation of bacteria and enzymes, loss of nutrients and aroma. Additionally, drying processes are highly energy consuming, representing about 20-25% of the energy used in food processing industry [9,11]. The objectives of an energy efficient process and the highest possible product quality are conflicting in many cases. Optimization allows the explicit formulation of energy and quality objectives, and will therefore have a large potential in enhancing the operation of drying processes [10].

In the optimal control of drying of biological material, the quality of the material is the most important aspect. Since dried products are used in various situations and in various forms, it is obvious that the corresponding quality attributes are different. The quality attributes are linked to measurable quality indicators. Among many factors affecting the quality indicators, the most important are temperature and moisture content. As during the drying process, gradients of moisture content and temperature arise inside the material, the temperature and moisture distributions characterize the quality indicator rather than the average moisture content and average material temperature [12]. For instance, in the case of medicinal plants preservation, prevention of microbiological deterioration or the growth of organisms that could give rise to product poisoning is achieved by not exceeding a safe moisture content which is based on the local moisture concentration. Consequently, the quality of biological material is based on the local evolution of moisture and temperature profiles in the materials, irrespective of the defined quality indicator [11,13].

Several drying techniques have been proposed in order to rationalize the use of energy, as well as to reduce the negative effects of quality during the drying process. These effects could be cracks, fissures, non-enzymatic browning of fruits and vegetables, and lose of essential oils. One of these techniques is the intermittent drying [9,13]. This process alternates drying periods with rest or relaxation periods. The rest period (nondrying, tempering) allows homogenization of moisture through cooling. This applies to intermittent drying only in period when the drying rate is decreasing.

This simplified classification of the intermittency types is based on a literature reviews. The values of the focused used variables, like temperature, humidity, velocity and pressure, can be changed. The intermittency of these variables should not be chosen arbitrarily, rather it has to be selected based on the physics involved in the drying method, keeping in mind optimum energy efficiency and product quality. The development of new drying strategies for medicinal plants is required, so that it allows reaching the required quality characteristics and at the same time to have short drying times and low energy consumption. The strategies should consider an optimal balance between required quality and production costs.

The objectives of this research were to compare the conventional drying with the proposed stepwise drying, for lemon balm, considering drying time, energy consumption, color change of leaves and essential oil content, and additionally to determine the optimum change point of stepwise drying in terms of energy saving and reduction of drying time considering at the same time obtaining the quality characteristics.
2. Materials and Methods
The used sample of Lemon Balm (*Melissa officinalis* L.), variety citronella, was planted in a greenhouse in Witzenhausen (Germany). For this research two methods of drying were considered. The standard drying is conducted at only one temperature (40°C) and stepwise drying using two temperatures.

The drying experiments were conducted using a cabinet dryer developed by the company INNOTECH in close cooperation with the Hohenheim University. Due to the construction of the dryer and application of the over current principle a low airflow resistance is reached within the equipment. This results in a low energy requirement of the fan as well as the possibility to use cross flow fans. The application of this type of fans leads to a uniform air distribution in the drying chamber. In combination with the registered profiled layout of the trays there is no need to shift single trays during the drying process to reach the desired uniform drying rate.

The experimental data for the drying of Lemon Balm in a convective tray dryer was obtained in the first step at a low temperature (40°C) and in the final step with high temperature (50°C) and having different changes points corresponding to different moisture content of the product as shown in Figure 1 the amount of water removed during the drying process was determined by periodic weighting. A digital weighing apparatus (with resolution of ±0.001g) measures the mass loss of the product during the drying process. During each drying experiment, the weight of the products on the tray was measured. These measurements were undertaken every 10 min the first hour of the experiment and then at every 60 minutes until products reach the humidity level of 10%. This process had to be done fast in order to avoid the re-absorption of water from the environment [10].

![Figure 1: Drying methods considered in the study: standard drying and stepwise drying](image)

The different change points of temperature, considered in the research, are related to the moisture of product in a wet basis. The first change point was taken at 50%, then to 40, 30 and finally to 20% since the process ends when the product is at 10% humidity.

During the drying process the moisture content loss of the product was measured by monitoring the weight until a moisture content of 10% is reached. Parallel, the consumed energy during the drying process was measured. The essential oil content and color change were determined before (fresh product) and then after (dried product) the drying process to be used as comparison for the results.

2.1 Moisture content
To determine the moisture content of Lemon Balm before and after drying, the oven method was
used. In this method the sample is placed inside an oven at 103°C (±2 °C) for 24 hours and the loss of weight is registered in order to determine the moisture content of the sample (Association of Official Analytical Chemists, 1990)

2.2 Color
The method used for measuring the color of leaves of Lemon Balm, before and after reached a 10% moisture content value with the drying process, was the same for all the experiments. For measurements, a Chroma Meter Minolta CR-400© was used. The chromameter was calibrated before the measurement by using a white ceramic plate as reference. Additionally a sample size of five leaves selected randomly was considered. Furthermore for measuring the color of fresh product the samples were taken the same day of the experiment. The evaluation of color was based on chromaticity values in the CIELAB color space. In the CIELAB system the L-axis is defined in a range between (0) and (100) which represents darkness (0) to lightness (100). The a-axis describes the green to red intensity on a negative to positive scale, while the b-axis is used in the same manner to describe the blue to yellow intensity.

The color is one of the most important factors to determine the quality of consumers and behind consumers of buying. Effect of stepwise drying methods have been investigated. For color measurements, leaves were separated from branch. To obtain the color change the norm DIN 6174 [15] was used. For the determination of color difference, the values of the reference sample were compared with each of the measurements of the samples of dried product. Later on the average of the color differences was calculated.

2.3 Essential oils
For the determination of the content of essential oil the method described in DAB 10 [17] was used. This method uses steam distillation with a special distillation device. To have a basis for comparison, this methodology is applied using 100g of fresh leaves in a liter of distilled water and 20g dry leaves was taken in 200ml of distilled water. The essential oil content in the samples is reported for 100g of dry matter for comparison there between. Losses of essential oil were calculated in percentage based on the difference of the essential oil content between the fresh leaves and samples taken from the dried material.

2.4 Energy
The energy consumption was measured by a Voltcraft Energy-check 3000 electrical monitor which was connected to the drying during each trial. Solids content was determined after each experiment by the oven drying method.

3. Results and analysis
Table 1. Shows the mass change with regard of time during the drying process on each of the change points.
Table 1. Mass change during drying time

| Time [min] | W50% [g] | Time [min] | W40% [g] | Time [min] | W30% [g] | Time [min] | W20% [g] | Time [min] | W10% [g] |
|------------|----------|------------|----------|------------|----------|------------|----------|------------|----------|
| 0          | 300.10   | 0          | 300.195  | 0          | 300.036  | 0          | 300.106  | 0          | 300.106  |
| 60         | 238.44   | 60         | 247.182  | 60         | 238.386  | 60         | 238.442  | 60         | 238.442  |
| 120        | 213.02   | 120        | 213.084  | 120        | 206.500  | 120        | 213.021  | 120        | 213.021  |
| 180        | 191.01   | 180        | 193.793  | 180        | 196.491  | 180        | 191.015  | 180        | 191.015  |
| 240        | 172.14   | 240        | 176.666  | 240        | 167.851  | 240        | 172.142  | 240        | 172.142  |
| 300        | 160.59   | 300        | 160.638  | 300        | 156.848  | 300        | 160.591  | 300        | 160.591  |
| 360        | 144.48   | 360        | 147.660  | 360        | 144.446  | 360        | 144.480  | 360        | 144.480  |
| 420        | 132.16   | 420        | 132.204  | 420        | 134.379  | 420        | 131.804  | 420        | 131.804  |
| 480        | 123.09   | 480        | 125.398  | 480        | 122.793  | 480        | 122.822  | 480        | 122.822  |
| 540        | 116.28   | 540        | 116.319  | 540        | 115.735  | 540        | 115.762  | 540        | 115.762  |
| 600        | 108.11   | 600        | 113.447  | 600        | 112.331  | 600        | 112.358  | 600        | 112.358  |
| 660        | 99.786   | 660        | 102.431  | 660        | 104.263  | 660        | 102.712  | 660        | 102.712  |
| 720        | 94.877   | 720        | 98.346   | 720        | 98.633   | 720        | 98.657   | 720        | 98.657   |
| 780        | 91.660   | 780        | 92.998   | 780        | 88.175   | 780        | 91.863   | 780        | 89.446   |
| 840        | 85.432   | 840        | 85.657   | 840        | 82.260   | 840        | 86.470   | 840        | 84.325   |
| 900        | 83.122   | 900        | 83.699   | 900        | 75.806   | 900        | 85.754   | 900        | 81.955   |
| 960        | 80.565   | 960        | 80.110   | 960        | 83.671   | 960        | 83.671   | 960        | 80.012   |
| 1020       | 78.332   | 1020       | 78.954   | 1020       | 79.877   | 1020       | 79.877   | 1020       | 78.645   |
| 1080       | 76.110   | 1080       | 75.984   | 1080       | 83.9   | 1080       | 75.655   | 1080       | 76.227   |

In Figure 2, the drying curves corresponding to standard drying, for drying air temperature of 40°C, and stepwise drying combination of 40°C/50°C, considering different change points, are presented.

A considerable decrease on drying time compare to standard drying is observed. As seen in Figure 2, for all temperature changing points the drying time decreased compared to the standard to up until a maximum of 51% of time at 50% of humidity. The minimum decrease of drying time was 26% at humidity at 20%.

To analyze the change on color and essential oil content, the values for standard drying were considered as reference. In Figure 3, it can be observed that when the change point is higher, the change on color increases and the essential oil content decreases.
Moisture content, \% wb

Essential oil content, ml/100 g dm

Drying time, min

Figure 2: Considered drying methods: standard 40°C and stepwise 40°C/50°C

For standard drying, the obtained essential oil content was 0.17 ml/100 gr dm (dried matter) and the color change was \( \Delta E = 12 \). In contrast for stepwise drying with change points of 50\%, the essential oil content was 0.06 ml/100 gr dm, which corresponds to the largest loss of essential oil observed (near 65\% of the reference value). Regarding the color change, for stepwise drying with change point 50\%, \( \Delta E = 22 \) was obtained, which was the largest color change observed.

Figure 3: Color change and essentials oil content for different change points of the stepwise drying (40°C/50°C) compared with standard drying (40°C).

To analyze the consumed energy and drying time, the values for standard drying were considered as reference. In Figure 4 shows the behavior of drying time and consumed energy in the process for different change points of the stepwise drying compared with the standard drying. It can observed that if the change points increases, both the drying time and the consume energy decreases. For standard drying, the consumed energy was 4.25 kWh and the drying time was 1140 minutes. In comparison, for stepwise drying with change points of 50\% the consumed energy was 3.07 kWh, which corresponds to a reduction of 28.5\%. Regarding the drying time, for stepwise drying with
change point 50% was 537 minutes, corresponding to a decrease of 53% in comparison with standard drying.

Figure 4: Drying time and consumed energy for different change points of the stepwise drying (40°C/50°C) compared with standard drying (40°C).

4. Conclusions
A decrease in drying time for all changes points in comparison to the standard drying was observed. The lowest energy consumption and shortest drying time was observed for change point 50%. A decrease of 50.6% in drying time can be reached together with a reduction of 28% in consumed energy compared with conventional drying at no changes in quality. But in terms of quality, the change point 50% shows high color change and the lowest content of essential oil, being this the least effective method.

The combination 40°/50°C, for change point 20% shows nearly no color change and the same essential oil content of standard drying, which makes it the most adequate combination in terms of quality. In terms of energy this combination reduces the energy consumption by 10% regarding the standard. The drying time was reduced by 28.5%.

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