Comparison of Microwave Vacuum-, Freeze- and Hot-Air Drying by Energy Efficiency and Aroma Composition of Dried Hop *(Humulus lupulus)*

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***Abstract*—In this study, 3 different drying methods (hot-air drying, freeze drying, microwave vacuum drying) were compared by aroma composition of dried hops and the required electrical energy for each technology. From the total volatile fraction, 3 main compounds were detected: ß-myrcene, α-caryophyllene and ß-caryophyllene. According to the results, the 3 drying technologies did not cause significant change in aroma compound composition in dried hop. ß-myrcene was preserved in the largest amount by freeze drying, followed by microwave vacuum drying and hot-air drying, respectively. Freeze drying had by far the highest energy consumption, followed by microwave vacuum drying. Hot-air drying used the less energy, which is 5.96% of freeze drying. Microwave vacuum drying could be a promising alternative to widely used hot-air drying for hop, because of better aroma retention and slightly higher required electric energy.**

***Index Terms*—drying, microwave vacuum drying, freeze drying, hot-air drying, hop drying**

I. Introduction

Hop is one of the most important components of beer brewing, which can be used in different forms. The most used form is granules, but leaf hops and as a minority, fresh hops are used as well. During the processing of different products of hops, drying is a very important step. The main goal of drying is the inhibition of spoilage, caused by mold and mildew; however it also aids the retention of α-acids and other lupulinic resins, and protects against oxidation as well. Until now, the drying step is mostly carried out by conventional hot-air drying, which requires precise parameter settings (e.g. air temperature, air flow) in order to maintain quality properties while reaching proper moisture content [1]. The drying of hops always reduce the amount of aroma-providing essential oil, usually without noticeably affecting its composition [2].

Microwave Vacuum Drying (MVD) is a novel and mild drying technology, which causes the rapid and efficient removal of moisture content in foodstuff. Its main property is higher drying ratio compared to conventional hot-air drying, caused by the rapid evaporation of moisture content in vacuum. Using microwaves for heating results high thermal efficiency, therefore lower operational costs. The intense heating by microwaves and the low boiling point caused by vacuum makes the materials to dry for short time and at low temperature. These circumstances aid the high degree of retention of aroma and nutritional compounds beneficial to health [3].

During drying, the moisture content of raw material directly evaporates, causing an expansive force, which bloats the product. After the rapid removal of evaporated moisture content, the product hardens while cooling and gains a porous crunchy texture. Former research results showed that this consistency is a very attractive sensory property [4]. This property could be advantageous in brewing as well, because wort could contact in larger surface with unfold lupulin containing dried hops.

Microwave vacuum drying is a strong competitor to freeze drying, which is very expensive to operate, however it creates high quality products, particularly related to aroma content.

In this study, 3 different drying methods (hot-air drying, freeze drying, microwave vacuum drying) were compared by the aroma composition of dried hops and the required electrical energy for each technology.

II. Materials and Methods

Centennial variety hop (*Humulus lupulus*) was chosen for drying experiment because it is used as a double-purpose hop. It has high α-acid content, which makes it appropriate for bittering, but the more important property is Centennial has high aroma content as well, which makes it ideal for aroma- and dry hopping. The hop was grown in Budapest, Hungary. After the harvest, one part of the raw cones were frozen, the rest were dried immediately. The cones (moisture content: 69.11±1.10 %) were dried with 3 different methods, and then aromatic composition was measured by GC-MS.

Hot-air drying was carried out with a 400 dm^3 volume laboratory-scale L-MIM 320 type drier (Hungary) at low temperature (30 ℃) for 10 hours. The final moisture content was 22.56±1.41 %.

For freeze drying, a Christ A 1-4 LSC type appliance (Germany) was used. After a -80 ℃ rapid freezing, the

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sample was placed into electric heated trays. The main drying course took 16 hours at 103 Pa vacuum. The plates are continuously being heated until the samples reach 20 ℃. The second phase took for 2 hours, where vacuum value was decreased to 5.5 Pa. At the end of the second phase, the cones reached their final moisture content at 7.86±0.64 %.

Microwave vacuum drying was done by a uniquely designed microwave vacuum drying equipment as shown in former studies [5], [6]. It consists of a cylindrical stainless steel vacuum chamber, equipped with a conical dome for better vapor removal. 230 grams of hop cones were placed in a rotary Teflon (PTFE) tray. Microwaves are generated by two, 850W nominal efficiency magnetrons. The vacuum is kept constant at 5 kPa by a vacuum pump, connected to the heat exchanger for vapor condensation. The cooling water for the heat exchanger is cooled by a compressor and kept circulating by a pump. The samples were treated with 1836 kJ total energy input, which equals 7.98 kJ/g specific energy input. At the end of the process, the final temperature was 35 ℃ and final moisture content was 17.75±0.68 %.

At each drying technology, an automatic electric consumption measurement device was applied. The device displays the electrical consumption in kWh.

Raw cones and dried samples were put to a vapor- and aroma-sealing triplex foil package and were kept refrigerated at -18 ℃ until aroma analysis.

Before aroma analysis, half of the frozen raw cones were kept at 30 ℃ for 14 hours until they reached air-dry moisture content; the other half was used in its original wet form.

Volatile content was determined by gas chromatography upon solid-phase microextraction (SPME). Thus, 0.5 g of minced hop cones was heated in a capped headspace vial at 50 ℃ for 30 min, then the SPME needle (100 µm polydimethylsiloxane (PDMS) coated fused silica fibre, Supelco, USA) was exposed at 50 ℃ for 30 min. In the GC injection port the volatiles were desorbed at 250 ℃ [7]. For the analysis of volatile compounds a 5971 MS detector and a HP 5890/II gas chromatograph were used with a 30 m x 0.25 mm x 0.25 µm RH-5ms+ capillary GC column. Helium (4.8) was used as a carrier gas with the flow rate of 30 cm/s. The detection was executed in the 35-350 mass range. After individual background correction, an MS identification spectrum library (Wiley275.L spectrum library) was applied to recognize individual volatile compounds [8].

III. Results

Fig. 1 shows the distribution of typical compounds as a function of percentage of total volatile fraction. The results showed that the 3 evaluated drying technologies did not cause significant change on aroma compound composition, compared to raw material. Lower retention time (more volatile) compounds typically had slightly higher concentration at raw sample, and higher retention time (less volatile) compounds had slightly higher concentration at raw dried sample. The phenomenon could be due to the higher moisture content in raw sample, where the evaporating water molecules carried volatile aroma compounds more easily during the heating at SPME absorption. As reported by several papers earlier, 3 main compounds were detected in raw and dried samples as well [9], [10]. ß-Myrcene, α-caryophyllene and ß-caryophyllene had an average of 38.65 %, 10.69 %, 8.99 %, from the total volatile fraction respectively. By comparing the different drying technologies, the following tendency can be seen: microwave vacuum- and freeze drying had higher percent of volatile ß-myrcene, while they contain lower percent of less volatile α-caryophyllene and ß-caryophyllene, compared to raw samples. The percentage of ß-myrcene, α-caryophyllene and ß-caryophyllene of hot-air dried samples are similar to raw ones.

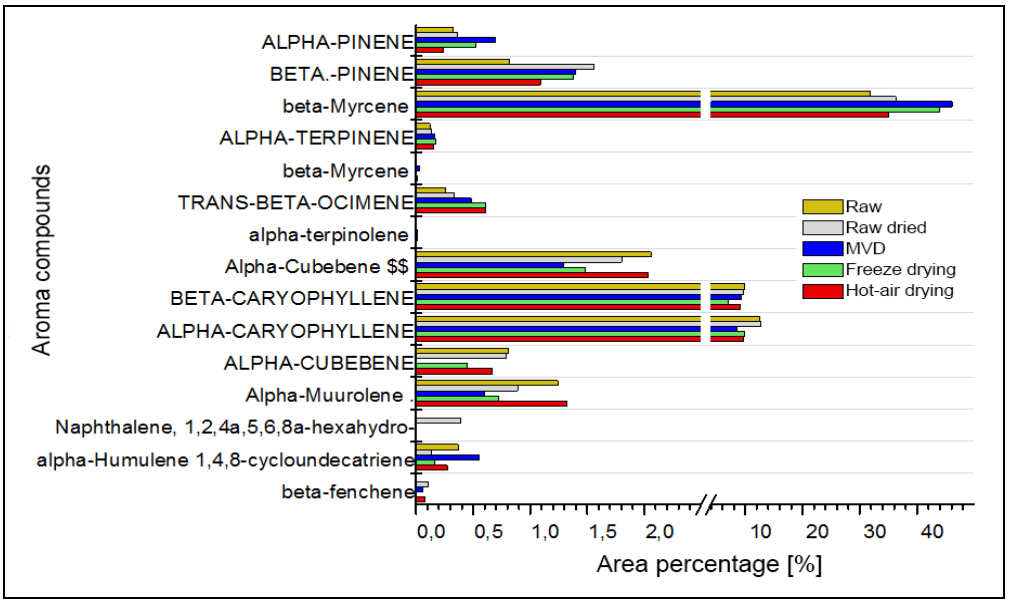

Figure 1. Area percentage of aroma compounds

Comparison of absolute peak areas is represented in Fig. 2, where different moisture content was not taken into account. Except ß-pinene, moisty raw sample had higher concentration of aroma compounds than its dried counterpart. Even if the weight of the samples for SPME was equal – which means more dry mass in case of dried sample – the dried raw sample has lost notable amount of aroma compounds as it lost moisture during drying. ß-myrcene – which is the largest amount presented compound in all samples, and is considered as one of the most potent odorant [11] – was preserved in the largest quantity by freeze drying, followed by microwave vacuum drying and hot-air drying, respectively. In case of α-humulene, the tendency is similar; freeze drying retained the largest quantity, followed by hot-air drying and microwave vacuum drying, respectively. Humulene and ß-caryophyllene amounts are almost identical at all samples. As for the higher retention time compounds (ß-Fenchene, α-Muurolene and α-cubebene), hot-air dried samples contained the most amount, followed by freeze drying and microwave vacuum drying, respectively. This phenomenom might be related to the relatively low temperature (30 ℃) used during hot-air drying. Freeze drying provided the most amount of aroma compounds from the lower retention time molecules, like trans-ß-ocimene, α-terpinene and ß-pinene. Comparing the summarized peak areas of evaluated compounds, freeze drying provided the most quantity of aroma compounds (2.59E+10) followed by microwave vacuum drying (2.10E+10) and then hot-air drying (1.98E+10).

None of the drying technologies caused any undesirable compound changes, like creation of new compounds or decomposition products. In this respect, microwave vacuum drying can be used safely for hops drying, which was not reported so far.

Energy consumption of each technology is depicted on Fig. 3. Freeze drying had by far the highest consumption with 15.09 kWh. Microwave vacuum drying required 1.27 kWh, which is 8.42 % of freeze drying. Hot-air drying used the less energy (0.90 kWh) which is 5.96% of freeze drying.

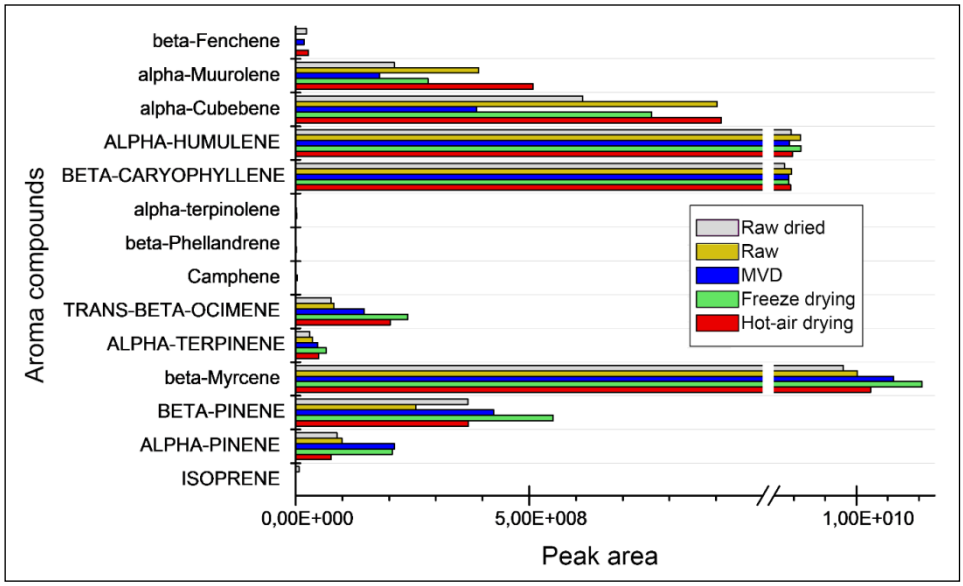

Figure 2. Area comparison of aroma compounds

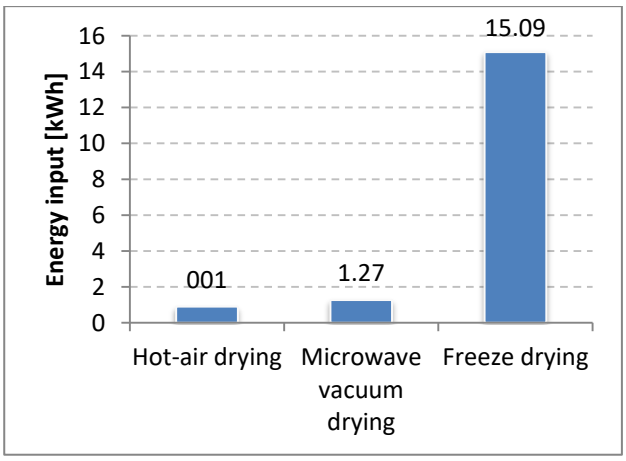

Figure 3. Energy consumption of drying technologies

IV. Conclusion

The 3 drying technologies did not cause significant change in aroma compound composition in dried hop. ß-myrcene was preserved in the largest amount by freeze drying, followed by microwave vacuum drying and hot-air drying, respectively.

Considering the aroma-holding capability and energy consumption of the 3 drying technologies, freeze drying is not a sustainable solution for hop drying because despite of the excellent aroma-holding property, its operation requires incomparably much electric energy. To commonly used hot-air drying, microwave vacuum drying could be a promising alternative, characterized by better aroma retention and slightly higher required electric energy.

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