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Effect of drying temperature in hop dryer on hop quality

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Abstract: One of the qualitative characteristics of both green and dried hops is the content of hop essential oils which are contained in a quantity of 0.5 to 3.5%, depending on the hop variety. These essential oils are heat labile substances because the temperature has an influence on their content. Hop cones, dried either in belt or chamber dryers, are exposed to a drying medium temperature of 55 to 60 °C for the entire duration of drying, i.e. for 6–8 hours. Under current drying conditions there is a loss of approx. 15 to 25% of the total content of essential oils present in hops before drying. In case of special aroma hop varieties, such losses lead to a decline in the product quality. Comparative measurements have been carried out with a laboratory equipment to find out whether more aromatic essential oils are retained in hop cones at a drying temperature of 40 °C compared to a drying temperature of 60 °C. The measurement carried out with the most common variety of Saaz hop concluded that the essential oil losses were lower by 33.4% at a drying temperature of 40 °C, and with other seven mostly hybrid varieties the losses were lower on average by 13.9% than at a drying temperature of 60 °C. The measurements proved that each of the varieties retained, to a significant extent, its content of essential oils in the dried hop cones at a drying temperature of 40 °C.

Key words: hop cones; hop drying; laboratory dryer; quality of hops

Drying is a widely used method of preservation of agricultural materials or foodstuffs. The success and sustainability of the drying process is determined by maintaining the quality of dried products, by the specific energy consumption, by ability to dry various moist materials, as well as by investment and operational costs (Kudra 2004; Lewicki 2006; Mujumdar 2006).

During the drying process water is removed as rapidly as possible from the material that is being dried, while preserving the product quality and minimising the energy consumption. No universal dryer has been developed, since every material requires specific drying as well as technological conditions. Historically, there have been developed and applied many types of dryers (over 400) using different drying methods, both in industry and agriculture (Mujumdar 2006; Tarhan et al. 2011).

Number of authors have examined various materials and their behaviour during drying in both theoretical and practical terms. Many studies have been conducted concerning mathematical modelling of drying processes and determining the kinetics of drying of different kinds of vegetables, fruits and medicinal plants. Winiczenko et al. (2018) experimentally examined the effects of drying temperature and air speed on various parameters, such as water absorption capacity, volume ratio and difference in colour as a result of applying convection drying. Beigi et al. (2017) examined the kinetics of drying raw rice with respect to specific values of energy consumption, drying and thermal efficiency. Kaveh et al. (2018) predicted convective drying parameters of various agricultural products by means of an adaptive inferential system of neural fusion and methods of artificial neural network. Przybyl et al.

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(2018) examined parameters of the quality of spray-dried strawberry juice. Zhang et al. (2015) proposed a method regulating the separation of temperature and relative humidity for control systems in dryers. Another teams dealing with the topic of numerical models and networks applied for drying are e.g. Youssefi et al. (2009), Şahinbaşkan and Köse (2010), Guine et al. (2015), Chokphoemphun and Chokphoemphun (2018), and Kirbaş et al. (2019).

It has been demonstrated that microwave drying reduces the drying period drastically, but it causes significant oil losses and colour changes (Tarhan et al. 2011). Microwave drying, however, is not used for the preservation of hops.

Many authors have dealt with the energy consumption during drying. As for the heat transfer, dryer permeability and material mixing, it has been found out that different drying methods have a direct impact on the specific energy consumption of dryers. Physical and chemical characteristics of moist materials, climatic conditions and operational possibilities (air recirculation, temperature of the materials to be dried) also influence the specific energy consumption. The specific energy consumption of laboratory dryers, which dry small quantities of material, tends to be much higher compared to the consumption of dryers used in normal operation. The specific energy consumption when drying garlic cloves in a laboratory dryer dropped from 164.33 to 85.45 MJ. kg of water^{-1} while the drying air temperature increased from 40 to 70 °C (Sharma and Prasad 2006). When drying carrot slices, the specific values of the energy consumption ranged between 12.22 and 14.58 MJ·kg of water^{-1} (Kocabiyik and Tezer 2009). The specific energy consumption of the dryers commonly used to dry medicinal plants in Germany ranged between 5.00 and 12.50 MJ·kg of water^{-1} (Mellmann and Furll 2008). The specific energy consumption when drying parsley in a belt dryer was 7.60 MJ·kg of water^{-1} (Bohner et al. 2009).

However, there are no studies dealing with the effect of temperature changes in drying medium on the product quality when drying hops.

Hops (*Humulus lupulus* Linnaeus) contain a lot of substances. There are several possible approaches to the assessment of hop quality, fresh or dried, for instance by measuring the moisture content, hop storage index (HSI), alpha and beta bitter acids, prenylflavonoids, humulinons or hop essential oils. Hop essential oils are the most significant group of substances contained in hops that are responsible for the hop aroma and as a part of medicinal products and food supplements they are also effective therapeutic means. Depending on the variety, hops contain 0.5 up to 3.0% of essential oils which accumulate together with resins and other substances in lupulin glands during the formation and maturation of cones (Doe and Menary 1979; Rybáček et al. 1980).

Hop essential oils are a compound of more than thousand natural volatile substances of different chemical composition (Schönberger and Kostelecký 2011). Some of them are present in the order of tens of percentages (myrcene, humulene), other occur in low or trace amounts. The components of essential oils divide into three groups. The largest share is represented by hydrocarbon fraction (monoterpenes) which forms 70–80% of the total weight of essential oils, oxygen fraction (terpene alcohols) then accounting for 20–30%. The remaining share relates to compounds containing sulphur (Schönberger and Kostelecký 2011; Krofta et al. 2017; Rettberg et al. 2018).

During the process of drying the hop cones, their moisture content decreases from its initial value ranging between 75 and 85% to the final moisture of dried hops which is 10–12%. Inside the dryer the hops are exposed to a drying temperature of 55–60 °C for 6–8 h applying the convection method of drying (Jech et al. 2011; Rybka et al. 2017). With this drying method the temperature is too high, especially in the final stage of drying. That is bad for some heat labile substances and it results in their losses.

The objective of this study was to find out about the effect of the drying medium temperature of 40 and 60 °C in hop dryer on preservation of the heat labile substances.

MATERIAL AND METHODS

The measurements, carried out during the whole harvest season of 2018, were to support the hypothesis that at a drying temperature of 40 °C, more aroma essential oils are preserved in hop cones compared to drying with the drying air temperature reaching 60 °C. For the purposes of our experiments we selected those hop varieties that are grown in the Czech Republic. We had designed and assembled the laboratory equipment to dry hops so as to reflect as much as possible the conditions for hop drying in the operating dryers of individual growers.

Material to be dried. For the purpose of our measurements several characteristic varieties of Czech hops had been selected: Saaz hop, Sladek, Premiant,

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Agnus, Harmonie, Rubin, Kazbek and Vital, which can be briefly described as follows:

Saaz hop is the principal variety of the Czech Republic with a long tradition and belongs to the group of fine aroma hops. In the Czech Republic it is grown on 85.19% of the total hop acreage (as at 20 August 2019).

Other varieties, such as Sladek (6.87%), Premiant (3.86%), Agnus (1.16%), Harmonie (0.16%) and Rubin (0.04%), began to be progressively cultivated since the mid-nineties. These varieties meet the condition for a higher content of alpha bitter acids and a higher yield, while in other characteristics they are close to the classical Saaz hop in terms of quality. New varieties seem to be especially suitable for so-called second hopping, and for the first hopping in case of the Agnus variety.

In 2008 another two varieties were registered. The first is Kazbek (0.66%), a variety of the aromatic type suitable e.g. for the second hopping not only for the traditional Czech beer types, but also for the foreign ones. Kazbek has its specific spicy-lemon aroma. This variety is also categorised as the "flavour hops" variety (aromatic hop varieties). The other variety registered in that year is Vital (0.06%). This is a bitter variety bred primarily for pharmaceutical purposes [high contents of xanthohumol or desmethylxanthohumol (DMX)]. In brewing it is used for the first and second hopping.

Dryer description. To fulfil the research objective, new laboratory equipment was assembled that included a chamber dryer (Figure 1). The chamber dryer had been selected due to better simulation of real drying conditions and simplicity of its construction. The laboratory equipment was assembled and installed in Chmelarstvi, cooperative Zatec. The whole equipment consists of these parts:

(*i*) a centrifugal fan RSH-500 (1) with an input of 1.5 kW (Janka Engineering, Inc., Czech Republic), which enabled changes in rotational frequency by means of a frequency converter,

(*ii*) an electric hot-air aggregate Thermobile VTB-18000 (9) with an input of 18 kW (Thermobile, Netherlands), for heating the drying medium to 40–60 °C,

(*iii*) a chamber dryer with a slat box with perforated bottom for storing hops (2) and measuring apparatus,

(*iv*) an axial fan APZC-630 (3) with an input of 1.5 kW (ZVVZ Machinery Co., Czech Republic) for air suction.

Figure 1 shows the location of individual measuring instruments that are specified as follows: air temperature and relative humidity under the hop layer – 2 × data logger COMET S3121 (6), air velocity under the hop layer – 2 × air velocity transmitter GSMU 575 (Greisinger, Inc., Germany) + display device GIA 2000 (7), air temperature and relative humidity above the hop layer – 2 × data logger COMET S3121 (4), air velocity above the hop layer – 2 × air velocity transmitter GSMU 575 (Greisinger, Inc.) + display device GIA 2000 (5), blown air

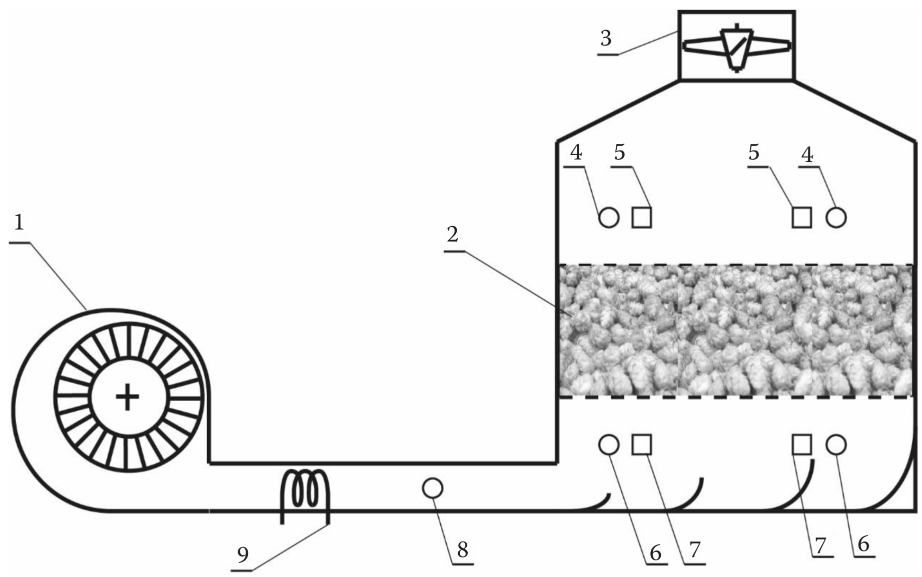

Figure 1. Scheme of the laboratory equipment for hop drying
For more details see Material and Methods, part Dryer description

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temperature – indicating and control unit BASPELIN KTR (Baspelin, Inc., Czech Republic) + cable temperature sensor Pt 100 (8), LKS energy consumption – electricity meter NOARK EDN 3412 (Noark Electric Europe, Inc., Czech Republic), burner energy consumption – electricity meter NOARK EDN 3412 (Noark Electric Europe, Inc.).

In addition, to continually measure the air temperature and relative humidity in a layer of hops to be dried, data loggers VOLTCRAFT DL-121-TH were used which enable to programme the frequency of data storage. In our case the frequency was set to 5 minutes. The analysis of the values obtained from continuous measurements was a subject of some other scientific article (Heřmánek et al. 2017).

Methodology for drying. After the hops had been picked, the fresh hop cones weighing about 21 kg were taken from the separation line at the Research farm in Steknik which is an integral part of the Hop Research Institute Co., Ltd. in Zatec. The hop cone sample was subsequently placed into a slat box of the chamber dryer measuring 0.9 × 0.9 × 0.3 m, filling it up completely. Thus, the height of the hop layer inside the slat box corresponded to the real hop layer to be dried in the operational belt dryer. On top of this slat box another one was placed which prevented the hop cones to be blown out of the first (bottom) slat box. Then the drying process took place at a selected temperature. In the experiments we monitored the moisture contents of fresh green hops at the beginning of the drying process as well as the moisture content at the final stage of drying, repeatedly and so that the drying stopped at 10% of hop moisture. The hop moisture content was always determined as the of three samples by means of the moisture analyser HE53 (Mettler-Toledo, Switzerland). The weight of the hop sample inside the slat box decreased to approximately one fourth of the initial weight.

Determination of the essential oil content. The laboratory analysis of the samples of each variety was carried out with green hops coming out of the separation line, which was used as a standard and their essential oil content was considered 100%. This was followed by a laboratory analysis of the samples of hops dried at a temperature of 40 °C as well as of the samples of hops dried at a temperature of 60 °C. These measurements were repeated three times and average values were determined from the results, while the dispersion of the values from the average did not exceed 6%.

The separation of essential oils from the hop matrix was carried out in a laboratory of the Hop Research Institute Co., Ltd. in Zatec in accordance with the certified methodology UKZUZ 122796/2017 (Krofta et al. 2017). The isolation of essential oils was implemented by steam distillation, when the mixture of water and finely ground hops boils for a defined period of time during which the volatile components of the essential oils in the steam bath condensate in a water cooler. Since they are lighter than water (specific weight ϱ = 850 kg·m^{-3}), they maintain on the surface of the water column where they can be easily separated (Vitázek and Havelka 2014).

RESULTS AND DISCUSSION

The selection of the varieties suitable for our measurements was based on recommendations made by the Hop Research Institute, Co., Ltd. in Zatec and Czech Beer and Malt Association. The Saaz hop was regarded as the basic variety, a kind of standard. Essential oil losses with this variety due to inconsiderate drying are of wider social significance. In global competition, even greater negative impact lies in a change in the hop cone sensory profile due to the decline in the volatile components. Other varieties selected for the measurement are grown on relatively small acreage, but they are among special aroma hop varieties for which their content and composition of the essential oils are the key qualitative parameters affecting significantly the product quality.

The drying air flow velocity was regulated by a frequency converter at the input fan so that it ranged between 0.95–1.20 m·s^{-1}, which corresponds to the parameters of an operational belt dryer. The air flow display devices enabled monitoring or possibly correcting the air flow velocity both under and under and above the hop layer. Balance of this speed depended on even distribution of hops in the slat box of the chamber dryer.

Electricity consumption at both drying temperatures rises in a linear manner with a minimal variability. Total electricity consumption with the most wide-spread variety of Saaz hop was 123.63 kWh for 10 h of drying to a moisture content of 10% at a drying temperature of 40 °C, compared to the total consumption of 122.43 kWh at 60 °C, but for a shorter time of 8 h of drying to that moisture content. As a result, electricity consumption at both temperatures is almost identical. However, the period with gentle drying is 2 h longer. The highest cumulative

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electricity consumption was measured with the hot-air aggregate – 13 kW·h^{-1} on average. The other appliances consumed 1.5 kW·h^{-1} on average, which is a negligible value within the overall consumption. The other varieties followed a similar pattern.

All the results of the laboratory analyses to determine the content of essential oils in the green cones obtained from the picking line and in the cones dried in the laboratory chamber dryer at temperatures of 40 a 60 °C are shown in Table 1. The moisture content of the fresh green hops at the beginning of drying was 75% for all varieties; samples were dried to a hop moisture of 10%; the drying time at a temperature of 60 °C was approx. 8 h and at a drying temperature of 40 °C it was 2 h longer. The energy performance in both cases of drying was identical.

From the obtained values two views of essential oil losses when using different drying methods have been processed and presented in a bar graph format.

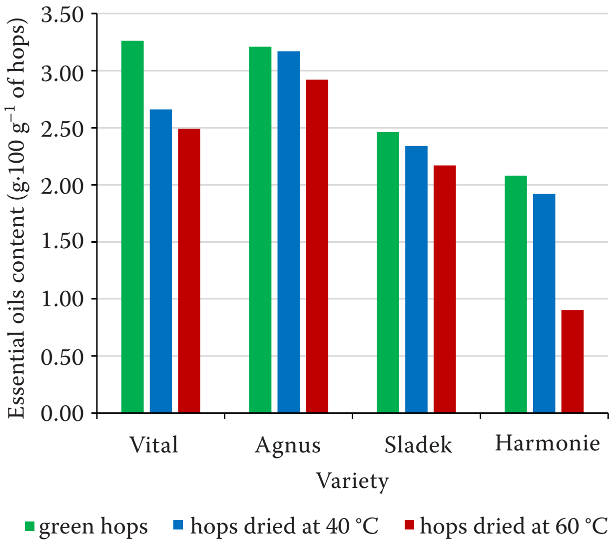

Figure 2. Changes in the essential oil content in 100 g of hops at a temperature of 40 and 60 °C compared to green hops

Table 1. Results of the laboratory analyses of the essential oil content in hop cones

Variety	Drying conditions	Amount of essential oils (g·100 g^{-1} of hops)	Relative proportions (%)	Essential oil losses (%)
Saaz	green hops	0.71	100.0	
	drying at 40 °C	0.61	86.4	13.6
	drying at 60 °C	0.37	53.0	47.0
Agnus	green hops	3.21	100.0	
	drying at 40 °C	3.17	98.6	1.4
	drying at 60 °C	2.92	90.8	9.2
Premiant	green hops	1.75	100.0	
	drying at 40 °C	1.46	83.4	16.6
	drying at 60 °C	1.34	76.8	23.2
Harmonie	green hops	2.08	100.0	
	drying at 40 °C	1.92	92.3	7.7
	drying at 60 °C	0.90	43.3	56.7
Rubin	green hops	1.71	100.0	
	drying at 40 °C	1.49	87.4	12.6
	drying at 60 °C	1.45	84.8	15.2
Kazbek	green hops	2.06	100.0	
	drying at 40 °C	1.89	92.0	8.0
	drying at 60 °C	1.50	72.8	27.2
Vital	green hops	3.26	100.0	
	drying at 40 °C	2.66	81.6	18.4
	drying at 60 °C	2.49	76.4	23.6
Sladek	green hops	2.46	100.0	
	drying at 40 °C	2.34	95.1	4.9
	drying at 60 °C	2.17	88.2	11.8

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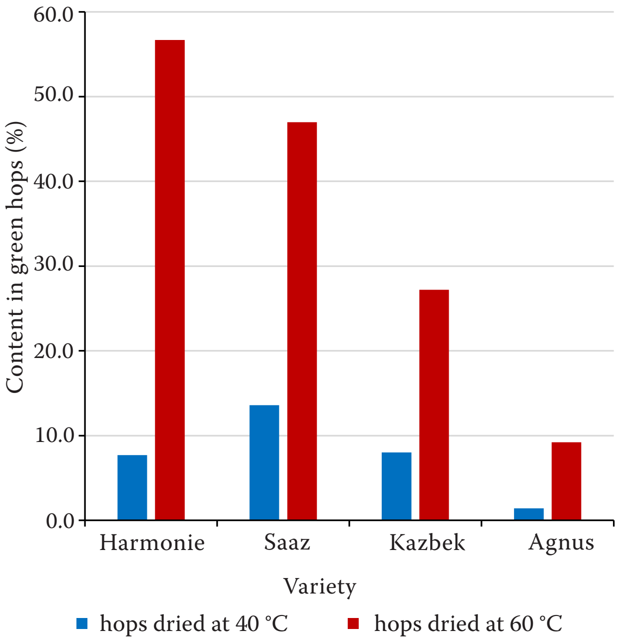

Figure 3. Relative decline in the essential oil (EO) content at a temperature of 40 and 60 °C compared to 100% content in green hops

Both graphs clearly show higher losses of essential oils at a drying temeperature of 60 °C.

The graph in Figure 2 shows 4 varieties that have the greatest representation of essential oils in green hops in absolute value, and also how the different drying reflects in their essential oil decline.

The graph in Figure 3 depicts 4 varieties with the biggest relative decline in the essential oil content compared to the 100% content of essential oils in green hops.

CONCLUSION

It has appeared from the measurements made that the quality of hops is significantly affected by the drying process in hop dryers. It has been proved that with all measured varieties dried at a temperature of 40 °C, the essential oil content in dried cones is substantially preserved compared to drying at a temperature of 60 °C.

The measurements made with the most widespread variety of Saaz hop resulted in lower essential oil losses by 33.4% at a drying temperature of 40 °C, and with other seven, mostly hybrid varieties, the losses were on average by 13.9% lower than at a drying temperature of 60 °C.

The selection of measured varieties had been intentionally supplemented by the varieties of Kazbek and Vital, as they are distinguished by specific characteristics in the portfolio of Czech varieties. Kazbek, owing to its unique aroma, is used for dry hopping, Vital is characterised by an exceptionally high DMX content due to which it is used for a production of phytopharmaceuticals and food supplements. Vital had the strongest absolute presence of essential oils in green hops of all measured varieties (Figure 2), and with Kazbek we recorded a severe relative drop in the essential oil content at a drying temperature of 60 °C (Figure 3).

On the basis of the measurements performed we can clearly conclude that gentle drying entails a decrease in the essential oil losses, without changing the essential oil composition in a substantial way, which has also been proved by experiments in recent years (Heřmánek et al. 2017).

A certain disadvantage of drying at 40 °C lies in the extended drying period by approx. 1/5, in order to dry the hop cones to a moisture content of approx. 10%. The electricity consumption was equal at both drying temperatures. The drying air velocity during the drying process was maintained at the values corresponding to the drying conditions of operational belt dryers.

Based on a confrontation with research work by foreign authors, a recommendation can be concluded to try short-term drying at temperatures of 60–75 °C at the beginning of a drying cycle (approx. 1–2 h) for a quick evaporation of the surface and free moisture, and then letting the hops dry completely in a gentle way at a drying temperature of 40 °C (Kořen et al. 2008; Krofta 2008). We assume that any follow-up measurements will move in this direction.

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