Impact of bulk weight on drying behaviour and hop quality after drying

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Abstract

Hops are a key ingredient for beer brewing due to their role in the creation of the foam characteristics, bitterness of the beers and aroma. Whilst in the past foam and bitterness were the key characteristics sought by the market, the last decade has seen a steep increase in demand of aroma hops for the production of crafts beers.

Color of the final product plays a major role in quality perception of traders and brewers. Therefore, color changes were investigated to estimate the impact of bulk weight and thus drying time and conditions on the upper surface of the bulk. A calibrated imaging system consisting of a CCD camera and illumination was integrated into the dryer. Further, changes of α and ß acid contents were investigated.

Hops of the variety Mandarina Bavaria were dried at 65°C and an air velocity of 0.35 m/s. Bulk weights investigated were 12, 20 and 40 kg/m² respectively. Drying times were 105, 135, and 195 min. Drying characteristics showed a unique development which very likely is due to the distinct physiology of hop cones (string, bracteole, bract, lupilin glands). Color changes depended strongly on the bulk weight and resulting bulk thickness whilst α and ß acid contents were not affected by the drying conditions. The research presented showed that air mass flow in relation to the mass of water to be removed is critical for the quality of the product as well as the processing time required.

Keywords: Hops, color, HSI, α and ß acid, drying

1. Introduction

Hop cultivation has a long tradition in Europe, first mentions date from about 1000 years ago. Initially, hops were mainly used to increase the microbiological stability of the beers. Over time, they have increasingly been used for other reasons such as foam quality, bitterness and aroma of the beers. Whilst bitterness is still the most important motivation for selecting certain types of hops, the new trends in crafts beer manufacturing means the aroma has received new attention.

Fresh hop cones are highly susceptible to rapid degradation and have to be processed within 4-6 hours after harvesting to retain optimum quality. The most commonly found preservation method for hops is convection drying during which the fresh hop cones are dried from initially around 80% to 10% desired final moisture content.

Bitterness is mainly created by components that are not volatile. However, aromas are highly volatile. Therefore, drying with the purpose of retention of aromas needs to fulfil different criteria than for protecting alpha and beta acids within the hop cones. The α and ß acids are secondary metabolites of the hops and are responsible for the bitterness of beers (Nagel et al., 2008). They mainly accumulate in the lupilin glands which lie between the braces of the cones (Priest and Stewart, 2006) and on the underside of young leaves (Kavalier et al., 2011). During storage, α acids in particular are susceptible to degradation. These changes can be expressed with the hop storage index HSI that has been used as a parameter for the evaluation of the freshness of hops and hop pellets. Cocuzza et al. (2013) showed in their research that the picking date has a significant influence on the HSI of fresh hops too.

Foster & Beck (1985) found that alpha acid losses are between 3.5 and 10% during drying, depending on the overall quality of the hops. Zeisig (1970) showed that an increase of loss by 5 % occurred, when the drying temperature was increased from 55 °C to 65 °C at constant air velocity. This is potentially related to a lack of sufficient air throughput in the transportation of the water and the bulk height within the dryer. Several previous studies on drying of sensitive agricultural products have shown that the impact of air velocity, and thus air mass flow, needs to be considered when evaluating optimization potentials for the process (Sturm et al. 2012 and Sturm et al. 2014).

In practice, air humidity regularly reaches 100 % which has direct negative effects on the quality of the hop cones that are exposed to these conditions. Firstly, the water which is transported to the surface of the cones cannot be removed from the surface and leads to color degradation. Secondly, these cones are highly likely to be colder than the surrounding air, which in turn leads to a re-condensation of a proportion of the water in the air and further increases discoloration.

The purpose of the research presented was the investigation of the dynamic changes of selected quality criteria, namely color, Hop Storage Index (HSI), α and ß acids, as well as product temperature throughout the drying process with different bulk weights.

2. Materials and Methods

2.1. System set-up

For the conduction of the research presented a pilot plant scale dryer with a drying area of 1 m² and an integrated heat recovery was used. The system was based on the basic system described by Hofmann et al. (2013) and modified by the introduction of an RGB camera, a hyperspectral system and the respective lighting installations (Crichton et al, 2016). The dryer was equipped with an array of temperature, humidity and air flow sensors to assess the temporal and special conditions within the system. Combined temperature/humidity probes were installed and positioned at different filling heights within the bulks to measure the development of temperatures and air humidity throughout the bulks. All values, except of the combined temperature/humidity probes, were transferred directly to a computer and stored.

2.2. Materials

Trials were conducted at the Research Station Hüll, Hallertau, Bavaria. Hops of the variety Mandarina Bavaria were used. All raw materials originated from the same hop garden close to the research station. Hops were harvested one hour before drying tests were conducted. Hop cones were separated from the vines using a commercial de-vining machine. The hop cones then were transferred into the dryer and drying tests were started immediately. The tests were conducted on five consecutive days in September 2015 to minimize variations in raw material quality due to harvest dates (Cocuzza et al., 2013).

Standard process settings used were 65 °C drying air temperature and 0.35 m/s air velocity. For the simulation of real conditions the bulk weight of the samples was used rather than the bulk height. Three different bulk weights (12, 20 and 40 kg/m²) were investigated.

The dryer was pre-heated to set temperature, then the hops were added into the dryer. Samples were taken at the start of the drying process, after 15, 25, 35, 45, 75 min and then every 30 min thereafter. RGB pictures were taken directly before the samples were removed from the dryer. Sampling was conducted on the surface of the bulk underneath the HSI system and the amount removed was replenished from other areas of the surface (1 m²). The calibration of this system is detailed in Section 2.4 and within Crichton et al. (2016). For sampling, a beaker of 2000 ml capacity was used and for each sample the equivalent of 1600 ml was removed. A small proportion was then used for dry matter assessment (24h, 105 °C) whilst the rest (ca. $1200ml_{eq}$) was vacuum packed and immediately frozen at -20 °C for chemical analysis. All tests were conducted in triplicate.

2.3. Chemical analysis and determination of the Hop Storage Index (HSI)

For the chemical analysis the frozen samples were freeze dried. Determination of HIS, α and ß acids was conducted according to the EBC Method 7.13 (EBC, 2007). Samples were extracted with toluene followed by dilution of the extract in methanol and alkaline methanol. The diluted solution was measured spectroscopically at 275nm, 325nm and 355 nm. HSI and α and ß acids' contents were determined using the following equations 1-3:

$$\mathrm{HSI} = \frac{\mathrm{A}\,275}{\mathrm{A}\,325} \quad (1)$$

$$\alpha = (-19.07 \cdot A275 + 73.79 \cdot A325 - 51.56 \cdot A335) \cdot F \quad (2)$$

$$\beta = (+5.10 \cdot A275 - 47.59 \cdot A325 + 55.57 \cdot A335) \cdot F \quad (3)$$

For the tests presented F was 0,667. To make the results comparable, the results for all water contents were normalised to 10% final water content.

2.4. Camera calibration

Color calibration of the RGB camera (The Imaging Source, Germany) using polynomial color correction (Finlayson et al., 2015a) was carried out. An X-Rite Color Checker Classic 24 patch chart (X-Rite Inc., Michigan, USA) was imaged using a set exposure under imaging conditions. Colorimteric data of each patch was then measured using a calibrated spectrometer (Q mini, RGB Photonics GmbH, Kelheim, Germany). Calculated XYZ values were then converted into CIELAB co-ordinates.

3. Results and Discussion

3.1. Drying behaviour

Figure 1 displays the drying curves of hops dried at different bulk weights. Bulk weight has a significant influence on the drying kinetics of hops. An increase in bulk weight increases the drying time of particles at the upper surface of the bulk.

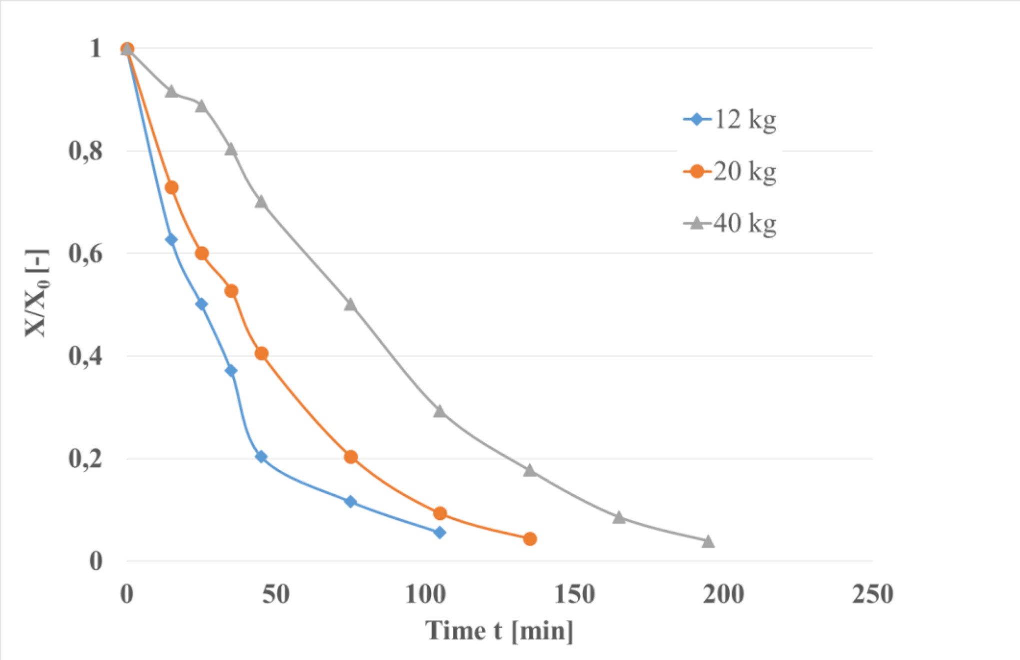

Figure 1: Drying curves of hop samples dried with different bulk weights

For all drying conditions there is a characteristic development of drying velocity with a rapid loss of moisture in the initial phase, a phase of reduced moisture loss and another increase thereafter before eventually transitioning into another phase of reduced drying velocity. This might be due to the structure of the hop cones: string, bracteole, bract, lupilin glands (Figure 2). Potentially, the string will only start drying once the leaves have reached a certain moisture content and thus develop a driving force through the increased moisture tension.

As a general rule, to reach the target moisture content of 10% the leaves are over dried to a moisture content of 6-8% whilst the spine still has a moisture content of around 12%. Thus, after drying a conditioning phase needs to be foreseen where the hop cones reach equilibrium.

Figure 2: Exemplary hop cones (a); cross section through a hop cone (b) and individual leaves and string (c) (Münsterer, 2015)

The ratios between string and body of the cone depends strongly on the variety in question and the stage of development. This in turn has a significant impact on the drying characteristics and the required conditioning time. Münsterer (2015) investigated 7 varieties to determine the ratio which was found to vary from 6.3-7.5% (Hallertauer Magnum) to 10.0-12.0% (Hallertauer mfr.).

3.2. Color changes

Figure 3 depicts the total color differences ΔE for the samples dried at different bulk weights.

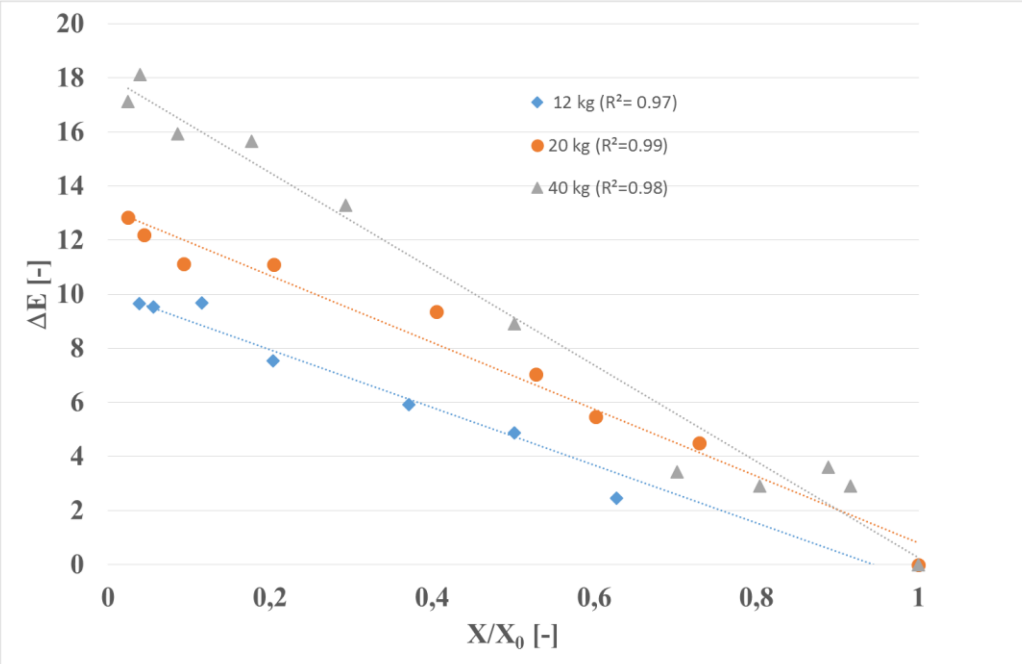

Figure 3: Total color difference ΔE for samples dried with 12 kg, 20 kg, and 40 kg bulk weight

An increase in bulk weight impacted the color changes of the different samples significantly. The changes can be represented through linear regression with a high degree of accuracy. The differences between the bulk weights can be directly correlated to the decrease of water removal potential of a given amount of air with increased bulk thickness. This is of particular importance during the first phase of drying.

3.3. Chemical components

Table 1 displays the HSI, α and ß acid contents for samples dried with 12, 20 and 40 kg/m² bulk weight. The results show that the drying process has no significant influence on the acid contents which is in line with the research of Foster & Beck (1985), who showed that losses during drying are very low. However, Zeisig (1970) stated that an increase in temperature from 55°C to 65°C leads to an increase in losses which could not be confirmed by this research as the levels stayed constant.

Table 1. Development of HSI, α and ß acid content of samples throughout the drying process

Time [min]	12 kg						20 kg						40 kg					
	HSI		alpha		ß		HSI		alpha		ß		HSI		alpha		ß	
		Std		Std		Std		Std		Std		Std		Std		Std		Std
0	0,220	0,004	8,43	0,69	7,79	0,31	0,220	0,009	8,59	0,38	7,85	0,47	0,215	0,002	8,28	0,58	7,56	0,70
15	0,211	0,002	8,18	0,68	7,75	0,35	0,219	0,005	8,41	0,14	7,98	0,10	0,217	0,002	8,90	0,29	7,79	0,09
25	0,219	0,006	8,82	0,71	7,90	0,16	0,220	0,003	8,82	0,77	8,17	0,04	0,221	0,005	9,88	0,40	8,80	0,17
35	0,213	0,013	8,64	1,16	7,73	0,57	0,220	0,001	8,28	0,86	8,14	0,23	0,222	0,006	9,55	0,38	8,45	0,45
45	0,215	0,009	8,97	0,76	8,00	0,50	0,216	0,008	8,67	1,03	7,98	0,14	0,216	0,006	9,94	0,30	8,60	0,36
75	0,228	0,012	8,42	0,84	7,38	0,60	0,232	0,002	8,48	0,68	8,09	0,49	0,213	0,006	9,56	0,85	8,43	0,66
105	0,225	0,002	8,51	0,42	7,70	0,11	0,229	0,004	7,82	0,29	7,62	0,12	0,210	0,006	8,86	0,49	7,67	0,12
135	0,229	0,001	8,64	0,69	7,62	0,32	0,234	0,004	8,56	0,43	7,77	0,26	0,220	0,001	9,06	0,42	7,91	0,18
165	0,230	0,015	8,30	0,89	7,73	0,42	0,235	0,004	8,63	0,66	7,83	0,13	0,224	0,001	9,54	0,41	8,23	0,04

The HSI as an index for freshness of the samples is low as expected, as the samples were processed within 60 minutes of harvest. Values between 0.21-0.24 indicate that the samples used were of constant quality and not influenced by the picking date.

The results indicate that, for the components investigated, the drying conditions are not critical. This in turn might help to explain why farmers have not struggled to meet the requirements on quality of bitter hops in terms of valuable components, as the α and ß acids' contents seem to be highly thermostable. However, it is to be expected, that this is not true for volatile components.

4. Conclusions

The results of the research undertaken show that bulk weight has a significant influence on both the drying time and the color changes of hops during drying at identical conditions. Air mass flow and air conditions in relation to the mass of water which needs to be removed was shown to be critical for the quality of the product. Thus, in practice, it is important to find the optimum compromise between process settings and scheduling on the one hand and acceptable color changes on the other. The contents of α and ß acid as well as the HSI were not impacted by the drying conditions and thus can be seen as non-critical parameters in terms of process optimization.

Further work needs to include the investigation of the losses of aromatic components which are highly volatile and thus susceptible to losses during drying. The characteristics of the drying curves need to be further investigated and the interactions between the leaves and the string modelled. Different drying temperatures and air velocities need to be investigated in terms of their impact on hop quality after drying.

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