

This article is from  
issue Number 2, 2013, of

# TECHNICAL *Quarterly*

published by the  
Master Brewers Association of the Americas

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# Influence of Picking Date on the Initial Hop Storage Index of Freshly Harvested Hops

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## ABSTRACT

The aim of this study was to focus on the varietal and seasonal differences found in the initial hop storage index (HSI) of freshly harvested hops. Standardized harvesting trials using major German aroma and bitter varieties were performed within the two crop years 2011 and 2012. During maturation, hops were analyzed several weeks prior to and after their usual picking date. It can be shown that picking date has an influence on the initial annual values of fresh and non-processed hops. In the varieties tested during the period of this study, initial average HSI ranged from 0.18 to 0.30, with a highest increase from first to last picking date of 0.10. As a consequence, higher initial HSI values do not necessarily indicate a higher deterioration rate of hops. The picking date and therefore the initial HSI of a certain variety and crop year should be considered for the evaluation hop freshness as well.

**Keywords:** hop maturation, hop storage index (HSI), picking date, spectrophotometric analyses

## SÍNTESIS

El objetivo de este estudio fue analizar las diferencias anuales y entre variedades encontradas en el índice de almacenamiento de lúpulo (IAL) de lúpulos recién cosechados. Se realizaron en los años 2011 y 2012 pruebas estandarizadas con respecto al modo de cosechar variedades importantes alemanas de lúpulos tipo aroma y tipo amargo. Los lúpulos fueron analizados durante su época de maduración, unas semanas antes de y unas semanas después de su fecha normal de cosechado. Se pudo demostrar que la fecha de cosechado influye sobre los valores iniciales anuales de lúpulos frescos no procesados. En las variedades testadas, el promedio inicial del IAL varió entre 0,18 y 0,30, siendo 0,10 el mayor aumento encontrado entre la primera y la última fecha de recolecta, por lo que un valor inicial mayor del IAL no implica necesariamente que habrá una mayor tasa de deterioro del lúpulo. Se debe considerar la fecha inicial de recolecta, y por tanto el valor inicial del IAL, de cada variedad y año de cosecha para la evaluación de la frescura del lúpulo.

**Palabras claves:** análisis espectrofotométrico, índice de almacenamiento de lúpulo (IAL), fecha de recolecta, maduración del lúpulo

## Introduction

For many years, the hop storage index (HSI) has been used as one of the parameters to evaluate the freshness of hops and hop pellets. The HSI is a non-dimensional number of two digits, calculated by dividing the adsorption of an alkaline methanolic extract of hops measured at the two different wavelengths of 275 nm and 325 nm using UV spectrophotometric analysis. At 325 nm, mainly adsorption of alpha and beta acids can be detected, whereas unspecific decomposition products from oxidation and further chemical reactions peak at 275 nm. Needless to say, further unspecified bitter components also contribute to certain adsorptions at any wavelength. During storage of hops, in particular, the concentration of alpha acids decreases while the quantity of degradation components generally increases (17,19). Hence, adsorptions measured by

spectrophotometric analysis are affected and the HSI ( $A_{275}/A_{325}$ ) respectively increases with longer storage of hops.

Besides HSI, other methods have been reported to evaluate freshness of hops or to identify specific aging indicators (2,6,9,10,14,15,18). Today, however, HSI is the most commonly used method worldwide.

In 1970, Likens and Nickerson published maturation trials from 1966 that were performed over one month. For the hop variety Bullion, these trials indicated an HSI of fresh picked samples ranging from 0.22 to 0.26 (12). However, the number of available hop varieties is increasing annually. Both the initial HSI and behavior during subsequent storage are variety specific (1,3,4). It is known that aroma varieties show a tendency toward lower storage stability (16). With regard to new varieties, breeding programs also focus on low HSI values (8).

Referring to Likens et al., the current method ASBC Hops-12 for the determination of HSI distinguishes between “stable” and “unstable” hops, having values assessed to be fresh ranging from 0.22 to 0.26 and from 0.32 to 0.79 for aged hops, respectively (1). Also, other values for fresh hops were reported in a range below 0.31 and below 0.38 in the case of hop pellets (2,4).

A lot of research has been carried out on parameters that increase HSI, such as drying conditions, bale compression, influence of oxygen, and storage temperature (11,16,20,21). These studies confirm that HSI shows a certain increase during storage, even if hops and hop products are stored correctly under

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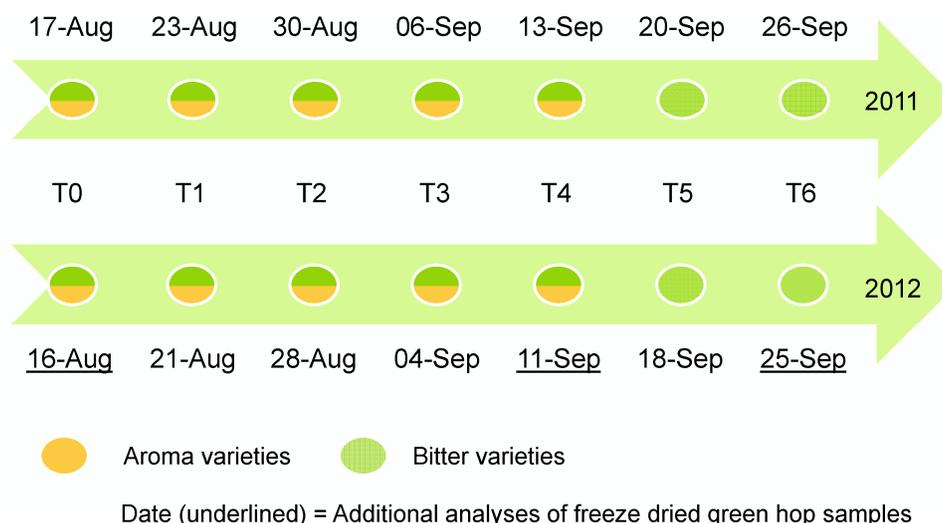
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**Table 1.** HSI of German bitter and aroma varieties over the last 10 years

Variety	Years <sup>a</sup>	Ø of HSI (previous crops)	Min	Max	Δ (max-min)	Ø 2011	Ø 2012
DEHM	10	0.26	0.24	0.28	0.04	0.28	0.26
DETU	10	0.27	0.23	0.29	0.06	0.28	0.27
DEHS	8	0.27	0.25	0.29	0.03	0.27	0.26
DEPE	10	0.27	0.24	0.28	0.04	0.27	0.28
DEHT	10	0.25	0.24	0.26	0.02	0.24	0.26
DESR	8	0.30	0.27	0.34	0.07	0.32	0.32

<sup>a</sup> Only 8 years in the case of DEHS and DESR due to later introduction.

**Figure 1.** Picking dates of tested hop varieties.

recommended conditions, such as low temperature and the absence of oxygen (3,6,7). Nowadays, these ideal conditions are commonly used in the state-of-the-art hop growing, storage, processing, and brewing industries. However, there is always an unavoidable delay until all hops from one season are processed and, after processing, until they are delivered to the breweries. But even once the hops and hop products are delivered, a certain quantity is always kept in stock prior to usage. In order to evaluate the freshness of hops and hop products at their time of usage, it is therefore necessary to know the initial HSI after harvesting or processing, respectively. The difference of HSI values between harvest and point of use provides information about the freshness of the hops or hop pellets.

According to in-house analyses over the last few crop years of freshly harvested hops from several growing regions, an inconsistent behavior of HSI could be observed for all varieties. On the one hand, various hop varieties within one crop year have varying initial HSI values directly after harvesting. On the other hand, the average of each variety showed no consistent initial HSI itself over the various crop years. The average HSI of internal analyses from previous crops resulted in a range of 0.25 to 0.30 for the varieties tested in this study, with the highest variation of 0.07 in case of the variety Saphir (DESR) (Table 1).

In order to find out more information about the development of HSI during maturation as well as the parameters that contribute to the initial HSI value of a specific variety, standardized harvesting trials were performed in cooperation with the Hop Research Center Hüll and the Research Center for Brewing and Food Quality of the Technical University Munich,

Weihenstephan. From the examination of two crop years, hop samples of six varieties from two separate locations in Hallertau were regularly taken from mid-August until the end of September. The results confirm an increase of HSI by picking later, which has already been reported by Virant and Majer, who exclusively examined the development of HSI after the normal picking date (20).

## Material and Methods

### Experimental Setup

The trials included the major German bitter varieties Magnum (DEHM), Hercules (DEHS), and Taurus (DETU), and the aroma varieties Perle (DEPE), Tradition (DEHT), and Saphir (DESR). Each variety was grown at both locations, Rohrbach (Ro) and Hüll (Hu), which represent typical variance of growing conditions in the Hallertau region regarding soil, climate, etc. The trials were set up for crops 2011 and 2012 and under exactly the same picking procedure, drying technique, sampling, and laboratory. The growing conditions in both years were comparable and representative for a good and normal season. Hence, the officially recommended period of picking certain hop varieties was almost the same in both years, and also, the sampling schedule for “too early” and “too late” picking (T0 and T4 or T6 respectively) varied by only 1 to 2 days. Figure 1 gives an overview of the 2 year trial setup.

Each crop year, a total of 72 samples were taken, representing each prolonged harvesting period; 30 samples of aroma hops (T0 to T4) and 42 samples of bitter hops owing to the longer picking period of bitter varieties (T0 to T6).

**Table 2.** HSI results of all taken hop samples. Gray shaded rows represent 2011; white rows represent 2012

Time	DEHM (Ro / Hu)	DEHS (Ro / Hu)	DETU (Ro / Hu)	DEPE (Ro / Hu)	DEHT (Ro / Hu)	DESR (Ro / Hu)
T0	0.18 / 0.21	0.21 / 0.20	0.18 / 0.21	0.25 / 0.22	0.19 / 0.18	0.25 / 0.20
	0.19 / 0.22	0.22 / 0.21	0.22 / 0.22	0.21 / 0.19	0.20 / 0.21	0.20 / 0.23
T1	0.23 / 0.22	0.23 / 0.23	0.23 / 0.23	0.22 / 0.22	0.22 / 0.21	0.21 / 0.23
	0.21 / 0.22	0.23 / 0.24	0.23 / 0.24	0.25 / 0.23	0.22 / 0.21	0.25 / 0.25
T2	0.25 / 0.24	0.25 / 0.24	0.25 / 0.24	0.25 / 0.22	0.19 / 0.22	0.20 / 0.20
	0.21 / 0.22	0.25 / 0.23	0.23 / 0.24	0.22 / 0.24	0.22 / 0.22	0.22 / 0.22
T3	0.26 / 0.23	0.25 / 0.26	0.24 / 0.24	0.25 / 0.24	0.21 / 0.21	0.26 / 0.22
	0.24 / 0.24	0.26 / 0.26	0.26 / 0.26	0.27 / 0.27	0.26 / 0.26	0.22 / 0.24
T4	0.25 / 0.23	0.26 / 0.25	0.24 / 0.23	0.25 / 0.23	0.22 / 0.23	0.24 / 0.24
	0.23 / 0.23	0.29 / 0.27	0.24 / 0.25	0.24 / 0.24	0.21 / 0.22	0.23 / 0.22
T5	0.25 / 0.23	0.26 / 0.25	0.25 / 0.24			
	0.24 / 0.24	0.25 / 0.25	0.25 / 0.25			
T6	0.27 / 0.27	0.30 / 0.28	0.27 / 0.27			
	0.24 / 0.25	0.25 / 0.25	0.25 / 0.25			

Furthermore, the influence of drying procedures was also examined. Freeze drying of freshly picked hop cones from crop 2012 was performed prior to their HSI analyses. By using this treatment, thermal impact on hops during the drying procedure was excluded.

Besides the influences of picking date and drying procedure, a comparison of HSI results with those from commercially grown and harvested hops were investigated in 2012. Two major representative varieties were examined, i.e., DEHS for bitter and DEPE for aroma hops. Multiple samples from two hop growers producing large quantities of the chosen varieties (consequently long picking periods) were taken daily during commercial harvesting season.

### Sample Preparation

On each picking date, single bines of the chosen hop varieties were harvested at both locations at the same time (13). Drying of hop cones was performed directly after picking and under standardized conditions. For approximately 12 h, the hop cones were dried by warm air at 63°C (145°F) until moisture content of 6 to 10% (w/w) was reached. The dried hop cone samples were immediately packed under vacuum and kept below 0°C (32°F) for less than 2 weeks until spectrophotometric analysis was performed. Prior to the analysis, all picked hop cones were ground and homogenized.

### Moisture Content

Moisture content was analyzed according to EBC 7.2 (5).

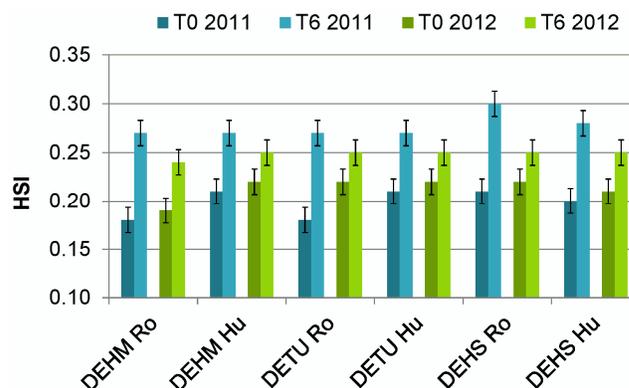
### Hop Storage Index

All taken samples were analyzed at the same laboratory of the Research Center for Brewing and Food Quality, TU Munich, Weihenstephan. The analyses were performed according to the current spectrophotometric method of ASBC Hops-12 (1).

All analyses were performed in duplicate and averaged values are diagrammed. The HSI results take into account an internal analytical error for repeatability ( $r$ ) of 0.026. Repeatability ( $r$ ) of the method was always higher than calculated standard deviation of single results ( $s = 0.012$ ). Therefore, the highest presumable deviation of  $\pm 0.013$  is shown for the bars in the following figures.

### Freeze Drying of Green Hops

Prior to freeze drying, samples were deep frozen at  $-22^{\circ}\text{C}$  ( $-8^{\circ}\text{F}$ ). The freeze drying procedure took about 21 h at  $-15^{\circ}\text{C}$

**Figure 2.** Bitter varieties T0 ↔ T6.

(5°F) until the target moisture content of 10% (w/w) was reached. Vacuum was held at 1.03 mbar. The equipment was manufactured by the company Christ, including system control unit LDC-1M.

## Results and Discussion

According to Figure 1, both crop years can be compared very well since the sampling schedule was almost the same in each case and the trial set up generally remained unchanged.

Table 2 shows all spectrophotometric results of HSI. Figures 2 through 6 are set up in a range of 0.10 to 0.35 on the Y-axis. The results are discussed in separate sections below.

### Bitter Varieties

Independent of crop year and location, an increase of HSI during maturation within 40 days (T0 to T6) can be observed for all tested bitter varieties (Fig. 2).

In 2011, the HSI values from the final picking date (T6) were in a range of 0.27 to 0.30. Comparing these HSI with the corresponding values in 2012, crop year 2011 generally tends to be at a higher level, at least toward the end of the trials. Except for varieties DEHM (Ro) and DEHS (Hu), differences from first to last picking dates are hardly distinguishable in 2012, but show an increase for all varieties in 2011. In this year, variety DEHS grown at Rohrbach reached the highest HSI of 0.30 at final picking, resulting in a difference of 0.09 from first to last picking date. The increase of 0.10 for DEHM (Ro) was the highest for all tested varieties. Comparing each

**Table 3.** Minimum and maximum HSI values and corresponding picking date<sup>a</sup>

	DEHM		DETU		DEHS		DEPE		DEHT		DESR	
	Ro	Hu										
2012												
HSI <sub>min</sub>	T0	T2										
HSI <sub>max</sub>	T6	T6	T3	T3	T4	T4	T3	T3	T3	T3	T1	T1
Δ (HSI <sub>max</sub> -HSI <sub>min</sub> )	0.05	0.03	0.04	0.04	0.07	0.06	0.06	0.05	0.06	0.08	0.05	0.03
HSI <sub>max</sub> -HSI <sub>T4/T6</sub>	-	-	0.01	0.01	0.04	0.02	0.05	0.04	0.03	0.03	0.02	0.03
2011												
HSI <sub>min</sub>	T0	T0	T0	T0	T0	T0	T1	T2	T2	T0	T2	T2
HSI <sub>max</sub>	T6	T6	T6	T6	T6	T6	T4	T3	T4	T4	T3	T4
Δ (HSI <sub>max</sub> -HSI <sub>min</sub> )	0.10	0.06	0.09	0.06	0.09	0.08	0.03	0.03	0.04	0.05	0.07	0.04
HSI <sub>max</sub> -HSI <sub>T4/T6</sub>	-	-	-	-	-	-	-	0.01	-	-	0.02	-

<sup>a</sup> Green: Earlier picking date, Yellow: Later picking date, Red: if max HSI was observed on latest picking date (T4 or T6 respectively).

**Table 4.** Comparison of picking dates for commercial harvest and trial schedule

Variety	Commercial harvest 2011 <sup>a</sup>	Trial schedule 2011 <sup>b</sup>	Commercial harvest 2012 <sup>a</sup>	Trial schedule 2012 <sup>b</sup>
DEHT	28-Aug	T2	27-Aug	T2
DEPE	1-Sep	T2	30-Aug	T2
DESR	1-Sep	T2	30-Aug	T2
DEHM	4-Sep	T3	2-Sep	T3
DETU	4-Sep	T3	3-Sep	T3
DEHS	12-Sep	T4	10-Sep	T4

<sup>a</sup> Officially recommended date to start the harvest season.

<sup>b</sup> Corresponding picking date of trial schedule.

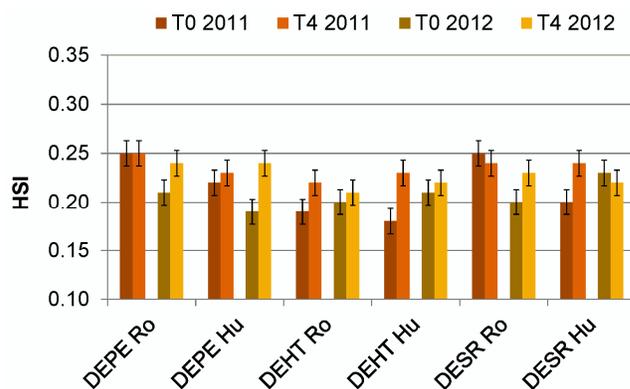
of the bitter hop varieties, DEHS reached inconsistent final HSI values in both crop years whereas DETU showed no distinguishable changes and DEHM showed both characteristics, depending on growing location.

In addition to the described tendencies, Table 3 compares the highest measured HSI during each year’s trial period with the corresponding picking date. In 2011, all bitter varieties had their lowest HSI in the beginning (T0) of the trials and peaked at their final picking date (T6). In 2012 again, the lowest HSI was observed at T0. However, only DEHM showed the highest HSI at T6 whereas other varieties peaked earlier, in case of DETU at T3 and DEHS at T4, respectively. Despite the described behavior, only the variance of 0.04 for DEHS (Ro) gives a clear measurable result comparing the latest and highest values (HSI<sub>max</sub>-HSI<sub>T6</sub>). The other differences of 0.01 and 0.02 are within the analytical error and therefore certainly do not indicate a peak earlier than T6.

In both crop years, T3 and T4, respectively, were the dates when technological ripeness was reached and commercial harvest was carried out (Table 4).

**Aroma Varieties**

The results of aroma varieties show less consistent tendencies compared with the bitter varieties (Fig. 3). The earlier picking date T0 can only be distinguished from latest picking date T4 in some cases. For DEPE, time of harvest had an influence in 2012, but not in 2011. The reversed behavior can be observed for DEHT. However, the crop year did not change the behavior of DESR, although the growing location did. When comparing bitter and aroma varieties, the latter unexpectedly had a generally lower HSI of maximum of 0.25. A reason for lower HSI results might be the shorter period of the trials. In the case of aroma hops, the trials were carried out over 28 days, 12 days less than for bitter hops, but both started on the



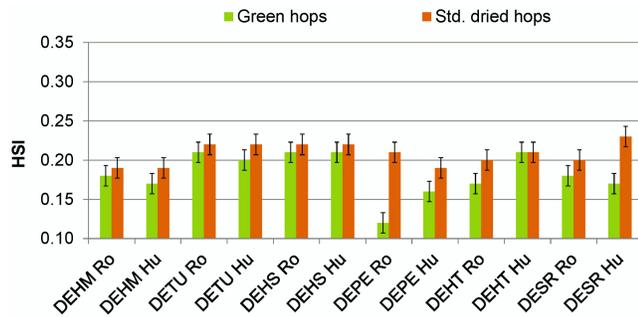
**Figure 3.** Aroma varieties T0 ↔ T4.

same day (T0). If the trials had been prolonged for aroma hops, the final HSI might have reached a similar level. However, especially in the case of DESR, the already performed HSI analyses of commercially harvested lots over the last 8 years indicated an HSI of 0.30 and more (Table 1). On the other hand, a lower HSI was confirmed for DEHT, as expected from previous commercially tested lots.

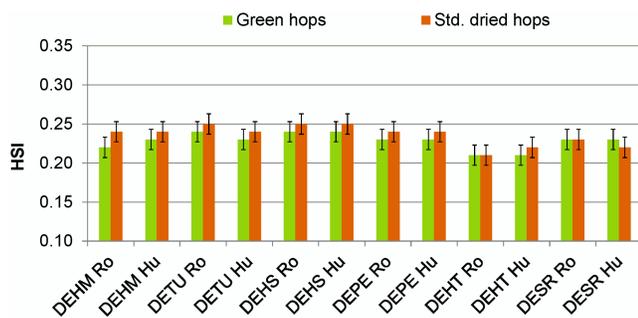
Table 3 indicates that, in 2011, the highest HSI was related to the later picking date, with no distinguishable difference between T3 and T4. Lowest HSI values were measured during the first period of the trials. DEHT (Hu) was the only variety for which the minimum HSI value was observed at T0. In 2012, DEPE and DEHT clearly peaked at T3, resulting in a maximum HSI increase ranging from 0.05 to 0.08. In this year, none of the aroma varieties reached their highest HSI values at the end of the trials and DESR grown in Hüll already peaked at T1. Without considering this result, in both crop years, the increase of HIS ranged from 0.03 to 0.07 and 0.08, respectively.

**Location**

In Table 2, the HSI at the beginning of the trials can be seen in the row T0. Variations between growing regions (Ro/Hu) can be found in six of 12 comparisons. However, all differences were balanced with the later picking date (see rows T4 and T6, respectively). Within the same crop year, an influence of the growing region is not given any more at the final picking date. Growing conditions seem to have less impact on HSI than time of harvest.



**Figure 4.** Comparison of green and standard dried hops at T0 (first picking date).



**Figure 5.** Comparison of green and standard dried hops at T6/4 (final picking date).

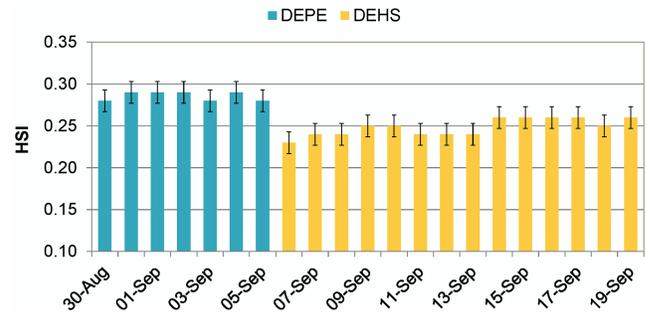
### Drying Conditions

The comparison of deep frozen standard dried hops is shown in Figures 4 and 5. In the case of T0 (Fig. 4), an increase in HSI can be shown only in DEPE (both Hu and Ro), DEHT (Ro), and DESR (Hu), resulting in the highest observable value of 0.23 in the case of the last named variety. The samples taken at the end (T4 and T6, respectively) show no further measurable variation (Fig. 5). With the exception of DESR (Hu), all varieties tend to show a slightly higher HSI after standardized drying procedure. However, the increase of HSI is small, within analytical error, and hence conclusions cannot be drawn.

Comparing first and last picking dates, the reason for the noticeable HSI increase might, in some cases, be the lower initial HSI at T0. The most likely degradation products of bitter acids are lower at the earlier stage of ripeness. Therefore, the impact of drying procedure might lead to a greater formation of these components and a noticeable increase of final HSI.

### Comparison – Commercial Harvest and Trial Results

The results of daily sampled, commercially harvested lots of DEHS and DEPE are shown in Figure 6. For DEPE, the harvest period was 1 week and 2 weeks in case of DEHS. Within the harvest time of DEPE, no change was observed, with both first and last HSI values at 0.28. None of the HSI values were outside of analytical variation. In relation to the commercial harvest period (August 30 to September 5), the value of 0.28 is close to the HSI of the trials for T2 and T3 (August 28 to September 4) and corresponds exactly to the annual average for this variety (Table 1).



**Figure 6.** HSI results of DEPE and DEHS in commercial harvest.

The examined commercial picking period for DEHS was from September 6 to September 19. Within these 14 days, HSI increased from 0.23 to 0.26. The results of DEHS demonstrate an increase in HSI with a longer picking period. Comparing the HSI of trials from T3 to T5 (average 0.26), which closely corresponds to the picking period of this variety, the correlation with the commercial harvest period is very good. The commercially sampled DEHS confirms the annual average for this variety.

## Conclusions

Trial varieties from two different locations and crop years showed an increase of HSI during maturation, except in the case of one sample (2011 DESR Hu). Later picking dates resulted in higher HSI levels. However, the highest values were not necessarily reached at the final picking date. HSI of bitter varieties unexpectedly increased to higher levels compared with aroma varieties and also showed higher increases during maturation. This may have been caused by the longer picking period in the case of bitter varieties. A comparison of trial results and commercial harvested hops indicated a very good correlation of observed initial HSI values during picking periods.

The impact of the drying procedure on fresh picked hop cones seems to be low. Measurable differences of freeze dried and kiln dried hops were only observed for hops that were picked too early, presumably due to less content of deterioration products at this early stage of maturation. With later picking dates, the drying procedure had no influence on initial HSI.

As harvest results do not focus on HSI, but rather on alpha acids and yield, HSI is a consequence of major criteria that determine picking time. Therefore, initial HSI values directly after harvest can vary. Furthermore, hop varieties generally vary within a certain range and also, annual fluctuations can be observed. Hence, fixed HSI values for the evaluation of freshness of hops are not meaningful. With regard to hop freshness, more parameters, such as picking date, have to be taken into account for the interpretation of a certain HSI value.

### ACKNOWLEDGMENTS

Special thanks to Max Krause and Rasso Hiltmann, both students at Weihenstephan, for their support of the trials, including their bachelor's and master's theses. Many thanks to Dr. Elisabeth Seigner and Jutta Kneidel (Hop Research Center Hüll, Germany) for joining the annual Biogenesis Studies, and also Dr. Fritz Jacob (Research Center for Brewing and Food Quality, Technical University Munich, Weihenstephan, Germany) for supervising the theses. Finally, the authors would like to thank Dr. Martin Biendl and Willi Mitter (both Hopsteiner) for their technical advice.

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