**INTRODUCTION**

Former hop sack, into which dry moistened hops are pressed, is a cylinder shaped of 0.6 m in diameter and 2 m high. Recently there has been a tendency to abandon hop sacks and prefer the automated pressing of hops into a bale (Fig. 1) sized 0.6 × 0.6 × 1.2 m (http://chmelarstvi-zavodmechanizace.cz/EN/hranolovy-lis.html). The main advantage of a bale compared to a sack is the maximum utilization of space both for transport and storage. Another advantage is a smaller volume of stored hops. A hop sack is pressed for a weight of approximately 60 kg, which at a volume of 0.635 m³ corresponds to a specific weight of 94.5 kg m⁻³. The bale is pressed for a weight of 50 kg and at a volume of 0.43 m³ it gives a specific weight of 115.7 kg m⁻³ of baled hops. Because of a higher specific weight, by 22% compared to a sack, there is a higher risk of mustiness for hops moistened by an air-conditioning line. After baling hops with a high moisture, the temperature relatively quickly increases and the surface cone moisture rises, an effect that is denoted as cone mustiness (Rybáček et al., 1980).

This process even more aggravates cone damage, which is high at a mechanized harvest. Drying and moistening of hops is in most cases carried out automatically, which complicates measuring the actual hop moisture (Rössbauer et al., 2003). At a high water content (15% and more) there arises a danger of rendering the hops worthless by becoming musty and in bigger volumes there is even a hazard of spontaneous ignition (Krofta, 2008). The temperature and moisture of too moist stored hops increase compared to loose hops. This is due to an increased intensity of hop cone breathing, release of H₂O and CO₂, and impossibility of the released energy outlet (Vent, 2012). An increased breathing intensity causes hop cones to lose important brewing substances, thus decreasing the quality of the final product. Besides, consumption of oxygen, which when lacking is gained intramolecularly through decomposition of organic substances, increases (Vent et al., 1963). Skinner et al. (1977) states that a decrease in the content of important brewing substances depends on storage time, amount of present air, and variety. According to Vi rant et al. (2003) the brewing quality of hops after storage is influenced...
by three basic elements: time, temperature, and cone damage. Hop mustiness is generally prevented by a lower moistening of baled hops. The lower moisture though causes a high percentage of cone shatter. When overdried, cones become fragile and easily crushing at mechanical strain. Overdrying of little cones may occur also at an uneven cone size (Krofta, 2008). When hops are overdried, their quality declines, and also moistening before baling becomes more difficult (Rossbauer et al., 2003).

**MATERIAL AND METHODS**

The measurement was carried out in August 2012 on PSH 750 belt hop dryer (Nové Mesto nad Váhom, Slovakia) in Oploty run by Chmel-Vent s.r.o. For statistical assessment of results three bales for each variant were prepared. A bale is a rectangular package measuring 0.6 × 0.6 × 1.2 m into which dry hops are pressed by HL-60/M (Chmelarstvi družstvo Zatec, hop machinery, Zatec, Czech republic) fully automated square bale press with a constant pressure. Each of the three bales contained hops with approximately known moisture, at which they were adjusted in advance in the air-conditioned line of the dryer. The driest hops with moisture of 9–10% were pressed into the bales for dry variant, hops with standard moisture of 11–12% were pressed into the bales for regular variant, and the bales for moist variant contained overmoistened hops with moisture of 13% and more. The hops were stored right in the space of the hop dryer (Fig. 1) where the temperature ranges from 7 to 40°C.

Moisture was measured by WILE 25 moisture meter (Farmcomp, Tuusula, Finland) in 8-h intervals. On the moisture meter there was a 45 cm long W-251 bar probe (FARMCOMP). The moisture meter did not have the logging function, so the data had to be recorded manually. Moisture was always measured twice with each bale. Once in the upper and once in the bottom part (Fig. 2), each time in the same spot, at a depth of 30 cm. The resulting moisture of a given bale was the average value of these two measurements. The measurements were carried out 3 times a day in 8-h
intervals over 10 days, each day at the same time – at 8 a.m., 4 p.m., and at midnight.

After the measurement had been finished, a sample was taken from each bale to conduct a laboratory analysis. With each sample we assessed its moisture content according to EBC 7.2 (ANALYTICA EBC, 1998), content of the α-bitter acid by conductometric value according to CSN 432520-15, and cone shatter according to CSN 46 2520-6 (CSN 46 2520, 1994). The measured data were processed and statistically assessed in STATISTICA (Version 10, 2011) program.

RESULTS

The initial values of moisture measured with the dry variant were 9.2, 9.4, and 9.5% with individual bales. With the regular variant the moisture of individual bales was 11.3, 11.3, and 11.6%. And finally the moisture values of the moist variant were 13.1, 13.3, and 16.2%. The last value is higher than was expected, however it did not have a negative impact on further measuring. The development of average daily moisture values for each variant can be seen in Fig. 3. At the beginning of the measurements there was a substantial difference in the moisture content (artificially created) between the individual variants which would gradually decrease in the course of time.

During days 7 and 8 of the measurement the difference between the dry and the regular variant was not even provable. The same case occurred on the last day of the measurement between the regular and the moist variant. As for the moisture development itself, Fig. 4 shows a slight increase with the dry variant and a considerable decline with the moist variant. The regular variant experienced a slight decline in the course of the measurement, but it was insignificant. The average speed of decline in moisture with the moist variant was 0.07% between individual intervals of the measurement. The most considerable decline (by 1%), was recorded on day 7 of the measurement and, on the contrary, one day later an increase by 0.87% occurred. With the regular variant we recorded an average decline of 0.01%. The fastest decline by 0.47% and increase by 0.83% occurred with this variant on day 9 of the measurement. The dry variant showed a substantial increase in the average moisture at the beginning of the measurement. During the first two days the moisture rose from 9.2 to 10.7%. The most considerable changes between the measurements were +1.53% and −1.1% which occurred on day 9 of measuring.

Fig. 4 clearly shows the development of moisture for each measured variant. By fitting the curves we discover that the moisture values of the dry and moist variants incline to the values of the regular variant. During 10 days of measuring all of the variants got in the moisture interval from 11.1 to 12.2% which makes a difference of 1.1%. The initial interval was from 9.2 to 14.4% which makes a difference of 5.2%. Unfortunately, the measurement did not go on. We can only use a theoretical estimation of the moisture development for each variant by prolonging the fit line. Then we discover (Fig. 4) that on day 14 of storage the moisture values of all the three variants would stabilize at a value of 11.3%. However, this estimation is merely theoretical.

The values of cone shatter and of the α-bitter acid content are shown in Fig. 5. Differences in cone shatter are significant. The driest variant showed the highest value of shatter, namely 28.2%. The regular variant had its percentage of shatter by 43% lower. With the moist variant the cone shatter was 16.6%, which is by 34% more than with the regular variant. If we look at the content of the α-bitter acid in the dry matter, there are no significant differences between the three variants. Both the dry and the regular variant have almost the same values, namely 3.76 and 3.93%, respectively. The moist variant has its α-bitter acid content slightly
higher (4.9%). Considering the value of correlation coefficient we may talk about a direct dependency of α-bitter acid on hop moisture, which is described in 69.7% by the given regression function. The value of the calculated significance is lower than the set significance level \( \alpha = 0.05 \), which makes it a statistically important correlation coefficient. The graphic depiction of the correlation field of the α-bitter acid content and moisture is seen in Fig. 6.

**DISCUSSION**

With their moisture, the dry and regular variants correspond to the parameters for a standard quality of hops. The moist variant falls into the non-standard category, because it exceeds the moisture value assessed by Market regulations for hops (12%) (Krofta, 2008). With the moist variant no expected increase in moisture and mustiness occurred. Mustiness did not occur neither with the sample showing the highest moisture (16.2%), which is more than presented by Krofta (2008). Dry hop cones have two adverse features: fragility and hygroscopicity. The hygroscopic feature caused a remarkable increase in moisture content of hop cones in the dry variant. Horješek et al. (1990) described the effect of air humidity on hop cones absorption of moisture from the atmosphere. The moisture content of hop cones increased from 10 to 12% during 5–7 days. The regular variant had its percentage of shatter by 34% lower, which corresponds to the statement of Rossbauer et al. (2003) and Krofta (2008) who claim that overdried hops bear the risk of higher cone shatter. Besides, no dependency of hop moisture on surrounding air temperature and moisture was proved, a fact which corresponds to the results of Vent (2012), who claims that increasing temperature and hop moisture in a container does not depend on the surrounding air temperature but on the storage time. The experiment was carried out under common conditions with the temperature ranging from 7 to 40°C which, according to Hopfenveredlung St. Johann (2001), does not correspond to a cool anaerobic environment suitable for storing hops. As proven by the results (Kroupa, 2003), to minimize qualitative loss it is necessary to process the baled hops into granules and store them in an air-conditioned environment.

**CONCLUSION**

From the measured results we may state that with dried hops moistened to 16.2% before pressing into a bale, neither moisture increase nor mustiness occurred. On the contrary, moisture of this sample declined after 10 days by 4.5%. With the dry variant the moisture increased by 1.5% during the storage. Considering the results of our measurement, the best variant appears to be the regular variant which did not show any significant changes in the course of the 10-day storage at the grower. It was a variant moistened for 11.3 up to 11.6% before baling. From the point of view of cone shatter the best proves to be again the regular variant. There was the lowest percentage of shattered cones, namely 12.3%. The shatter value is here by 43% lower than with the dry variant, and by 26% lower than with the moist variant. The α-bitter acid content in the dry matter was similar for all the variants and in this case a direct dependency on the hop moisture was proved. According to the classification into the quality range for Saaz semi-early red-bine hop, all of the samples are considered superior quality. The highest average content was with the moist variant, namely 4.9%.

**REFERENCES**


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