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The impact of weather conditions on microclimate in storage facilities

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Abstract. The key to maintaining good qualitative parameters of stored grain on farms is to achieve and maintain suitable storage temperatures relative to the outside temperature. In the framework of this research, the main focus was on typical representatives of grain storage facilities used in the Czech agriculture. In the post-harvest period after the crops were stored in the chosen storage facilities, the temperature of the material was monitored at 15-minute intervals using an external temperature probe as well as the temperature and dew point of the outdoor air. A simple linear regression model was used for data analysis. The correlated temperature dependence of the stored grain varies considerably in the monitored storage facilities. The storage halls were characterized by a low dependence (r = 0.2208) of the temperature of the material on the outside air temperature in the first 4 months following the harvest when the grains were being stabilized by active aeration. In addition to the grain and the air temperature, the second focus was monitoring the dew point, i.e. assessing the risk of water vapour condensation on the surface in the upper layer of the stored grain, which is very undesirable for maintaining the quality of the stored grain. The results show that the monitored storage hall can be characterized by the ability to maintain the required climate due to outdoor climatic conditions. In general, this ability mainly depends on the type and design of the storage facility, the aeration system and also the storage capacity. Mainly during spring the dew point and water vapour condensation can often happen within the grain, therefore the need to focus on appropriate measures such as reduced aeration or increased grain mixing, and thus avoiding the formation of critical spots.

Key words: grain storage, temperature variation, aeration, postharvest treatment.

INTRODUCTION

The supply of grain for food processing is seasonal due to the local weather conditions and possibilities of agriculture production, whereas the food industries require a continuous supply of raw materials (Laszlo & Adrian, 2009). This rises problems with logistic system and mainly with sophisticated storage areas. Achieving the necessary postharvest quality of stored grain is often the main problem in agricultural storage facilities. The qualitative indicators of produce are controlled and maintained during storage by adjustment of the physical environment. Lowering the temperature and water activity in stored grains is one task of climate control inside a storage facility so that the biological activity of the potential biological agents is minimised (Jia et al., 2001). Contamination or destruction of stored grains can be caused by insects, mites and fungi and their biological products. An important step for quality assurance is also the postharvest treatment (precise cleaning, sorting) and optimized transport routes in postharvest lines to prevent grain damage during this period (Skalický et al., 2008; Fourar-Belaifa et al., 2011).

Stored grains are living organisms which will react to their microclimatic conditions. Deterioration of stored grain may result from improper combinations of physical, chemical and biological variables (Cetiner et al., 2017). Heat, moisture and carbon-dioxide which are produced by respiration of undried grains and they promote the activities of decomposing organisms. The rate of reproduction and growth of these organisms is mostly dependent on temperature and moisture content of the grains (Capouchová et al., 2009). The grain forms an ecological system in which the grain and other organisms interact while being influenced by the ambient conditions (Polišenská et al., 2010). The knowledge of grain behaviour during storage, safety guidelines for storage, facility management and quality control procedures can be used to minimise quality loss in stored grain (Kibar, 2015). Low temperatures are important for maintaining the quality of the grains and ideal storage conditions in silos (Kibar, 2016).

Modern methods of storing grains are in silos (grain towers), storage halls or in small units (storage palette boxes, big bags etc.) which serve for seeding purposes or end producers. Among these, metal silos are the most preferred and built due to long-term protection effect on the stored grains. Furthermore, metal silos can take different shapes (mostly cylindrical or rectangular) and volumes from tens to thousands of tons (Skalický et al., 2008).

In comparison with storage halls, metal silos experience more moisture condensation resulting from temperature fluctuations within the silo and hot spots due to elevated temperatures in some parts often without the possibility to increase the aeration enough (Hammami et al., 2017). Storage halls can have bigger potential storage volume and possibility of better aeration because of smaller height of stored layer and variability in design of installed aeration ducts. Mathematical models can be developed for prediction of temperatures and moisture content at specific locations in the stored grains (Laszlo & Adrian, 2009; Casada, 2000; Jia et al., 2001). These models can be used to optimize the locations of sensors for detecting increased temperatures in stored grains.

Temperature distribution in the material is affected by multiple factors. Firstly, they are weather conditions such as ambient air temperature, air convection, solar radiation, location of the warehouse with respect to prevailing local wind direction. Second set are the structure, design and size of the warehouse. Convective heat transfer is not the only active heat transfer mechanism in a storage hall or silo. It should be noted that the unaccounted effect of ambient temperature and relative humidity on the bottom layer of the silo is equally of great significance (Yang et al., 2002).

In this article, the ability of a storage hall to maintain the required climate inside a as depending on outdoor climatic conditions was evaluated. To address these problems this storage facility had been equipped with an installation of sufficient aeration system with floor aeration ducts. Therefore, the objective of this research was to evaluate temperature changes inside the storage area and their dependence on climate conditions with statistical methods.

MATERIALS AND METHODS

A long-term storage experiment on a farm in the Central Bohemian Region monitored the impact of outdoor conditions on the microclimate within the storage environment and the consumption of electrical energy for aeration. The main stored products in this particular warehouse are wheat and malting barley. In the monitored period (2016–2017 season) 1,800 t of barley malt were stored in both halves of the storage hall i.e. 3600 t in total. The building length is 59 m and width is 19 m. There was used semi-circular aeration ducts with dimensions height 35 cm and width 65 cm, length of one section 90 cm, together 20 sections. Each aeration duct was connected to one medium pressure radial vent that provide 20–30 m^3 h^{-1} of air per tonne of stored grain and the required pressure of 1,500 Pa.

To measure the temperature of air between the grains, penetration probes with Pt1000 temperature sensors were installed in the material layer reaching to depth of 2.1 meters and placed 4 meters from the walls. The data was collected by a 4-channel Comet R3120 datalogger for long-term recording. A Comet S3631 datalogger was placed in the middle of the monitored part of the warehouse above the layer to record ambient air temperature and relative humidity, and one additional penetration probe to measure again the temperature at 2.1 m depth. The penetration temperature probes were placed so that they were not directly above any of the aeration ducts. Another Comet S3120 data logger was placed on the northern side of the storage building to measure the temperature and relative humidity of the outdoor environment in the immediate vicinity of the storage hall. Temperature variations within the storage hall over 12 month period in 2 storage seasons have been measured and evaluated.

We also measured the electric power consumption for aeration using a dual channel logger Comet S7021 with pulse and binary input to define how aeration influence inside temperature. The recording interval of all data loggers was set to 15 minutes. Arithmetic average of temperatures from the five measuring points was used to describe the temperature between grains at any given time. The dependencies between selected parameters were evaluated using linear regression,

$$y = a + bx\ (R^2), \qquad (1)$$

where y – dependent variable (daily temperature difference in grain, daily temperature in grain); a – y-intercept; b – slope of the line; x – independent variable (daily electric power consumption, daily outdoor temperature), R^2 – determination coefficient.

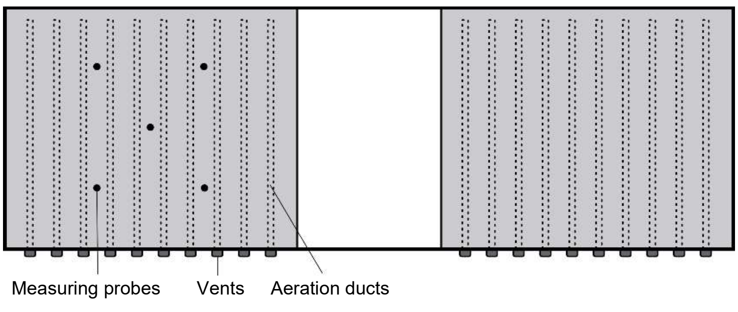

Figure 1. The measurement points in the storage hall viewed from above.

Fig. 1 shows the location of the probes inside the warehouse. The whole measurement took place in one half of the warehouse. About 1,800 t of malting barley was stored in the monitored portion.

The measured quantities: t_m – the air temperature inside the stored grain (measured at a depth of 2.1 m); t_{dpi} – dew point temperature in ambient air inside the warehouse; φ_i – relative ambient air humidity in the warehouse; t_e – outside air temperature; t_{dpe} – dew point temperature outside; φ_e – relative humidity outside; E – electric power consumption for aeration.

Technical data of used thermo-hygrometers Comet R3120, S3120, S3631: temperature measuring range -30 to 70 °C: accuracy 0.4 °C, accuracy of humidity measurement 2.5% RH, resolution of reading 0.1 °C, 0.1 RH.

RESULTS AND DISCUSSION

The monthly summaries of the monitored parameters of the indoor environment of the storage hall are shown in Tables 1–3.

Table 1. Monthly minimum values of the observed parameters of microclimatic conditions

Month/Year	t_m °C	t_{dpi} °C	φ_i %	t_e °C	t_{dpe} °C	φ_e %
7/2016	18.9	7.4	27.5	9.8	7.1	15.6
8/2016	15.8	3.6	20.2	6.8	4.8	24.7
9/2016	18.8	2.6	20	5.8	3.4	23.5
10/2016	19.5	0.2	29.1	1.8	0.7	27.8
11/2016	18.1	-8.8	34.6	-5	-9.2	34.4
12/2016	15.5	-11.1	33.5	-8.4	-11.1	41
1/2017	12.8	-17.7	44.5	-14.1	-18	53.4
2/2017	11.5	-10.1	25.3	-8	-10.4	32.3
8/2017	15.5	5.8	22.3	9.6	5.7	32.9
9/2017	16.5	3.3	33.5	6.6	3.6	44.1
10/2017	17.3	-2.8	34.1	0.5	-2.1	48.8
11/2017	16.7	-4.5	52.6	0	-3.8	63.7

Table 2. Monthly average values of the observed microclimatic conditions

Month/Year	t_m °C	t_{dpi} °C	φ_i %	t_e °C	t_{dpe} °C	φ_e %
7/2016	21.17	14.33	64.67	20.11	13.85	50.65
8/2016	20.9	12.29	59.92	18.9	12.2	49.21
9/2016	20.63	10.88	59.44	17.61	11.16	50
10/2016	20.5	5.61	80.58	8.02	6.01	67.07
11/2016	19.01	0.91	80.58	3.22	0.42	80.81
12/2016	16.75	-2.12	81.81	-0.01	-2.42	84.2
1/2017	14.4	-7.84	75.76	-5.23	-8.3	79.27
2/2017	12.03	-2.15	73.54	1.67	-2.64	74.45
8/2017	19.27	12.8	59.16	20.66	13.31	64.29
9/2017	17.82	8.88	74.75	12.88	9.23	79.5
10/2017	17.58	7.32	78.19	10.54	7.78	83.67
11/2017	17.09	1.88	83.27	4.29	2.42	87.96

Table 3. Monthly maximum values of the observed microclimatic conditions

Month/Year	t_m °C	t_{dpi} °C	φ_i %	t_e °C	t_{dpe} °C	φ_e %
7/2016	24.5	19.7	95.2	32.2	19	74.2
8/2016	30.9	23.7	95.4	30	19	75.5
9/2016	23	16.5	96.3	30.1	17.6	75.7
10/2016	21.3	12.1	97.7	23.2	12.2	78.8
11/2016	19.6	8.8	97.9	13.1	8.5	97.3
12/2016	18.2	6.7	94.7	9.8	6.6	96.5
1/2017	15.7	0.2	92.4	2.8	0	93.6
2/2017	12.9	6.7	96.2	12	6.7	95
8/2017	22	18.7	96.2	34	21.4	96.4
9/2017	19.3	15	98	21.9	15.6	99.1
10/2017	17.8	14.5	97.8	20.9	14.1	100
11/2017	17.4	7.2	97.3	12.4	7.9	100

Monthly temperature summaries inside the stored malting barley and outside temperatures are shown in Figs 2–3.

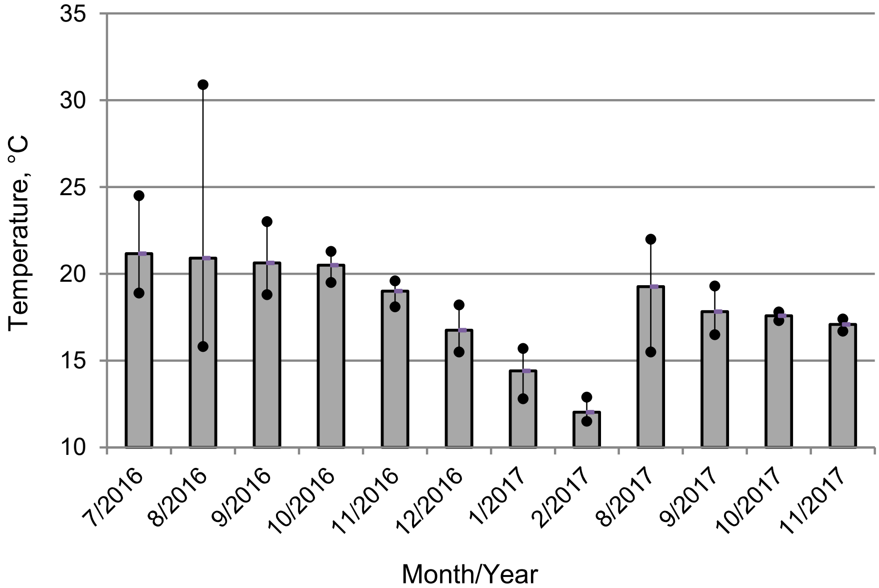

Figure 2. Monthly temperatures inside the stored malting barley layer.

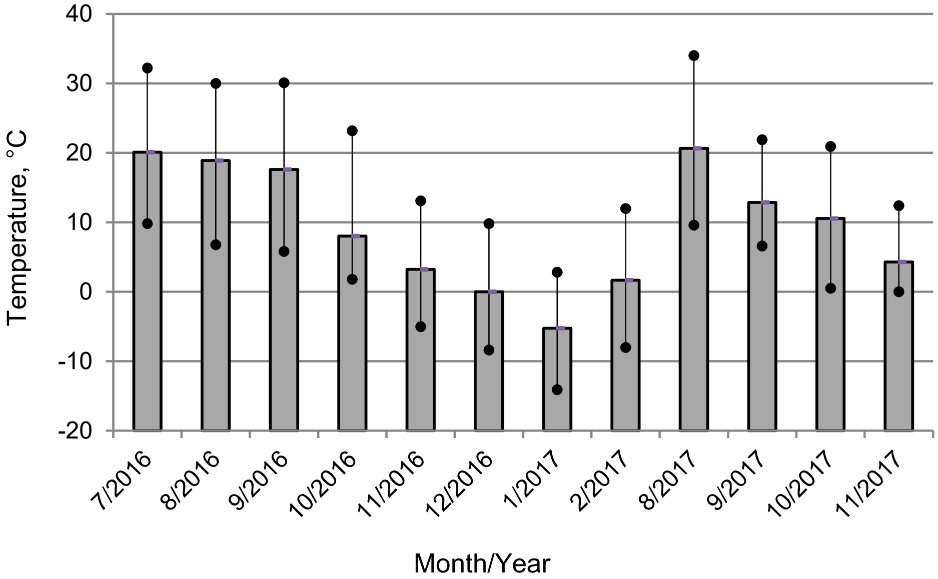

Figure 3. Monthly outside temperatures in the location of the observed storage facility.

The graph of average daily temperatures and the consumption of electrical energy for aeration during a period of storage is shown in Fig. 4.

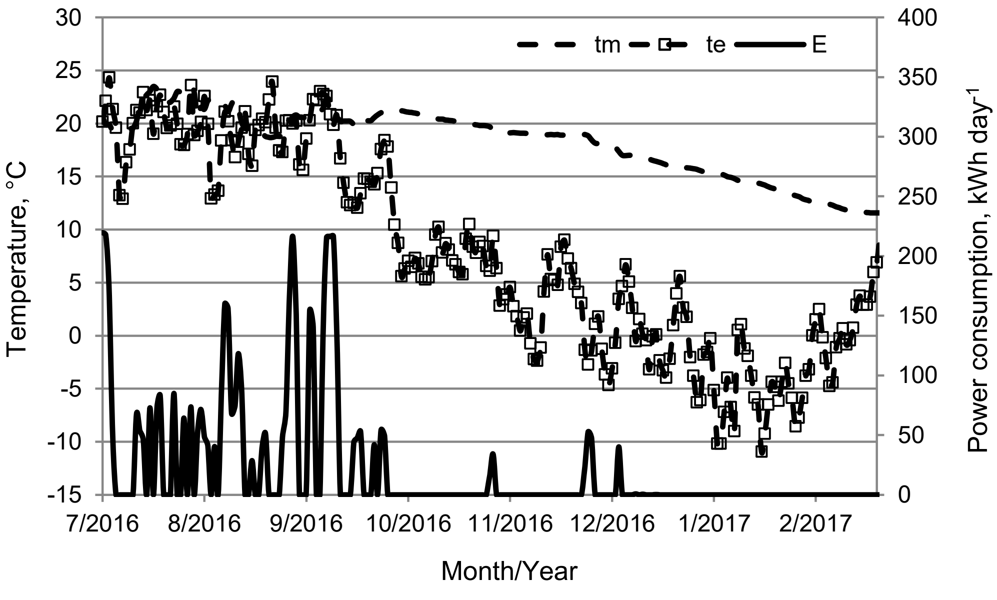

Figure 4. Daily average temperatures and electric power consumption for aeration.

Daily temperature difference and daily electric power consumption for aeration are shown in Fig. 5.

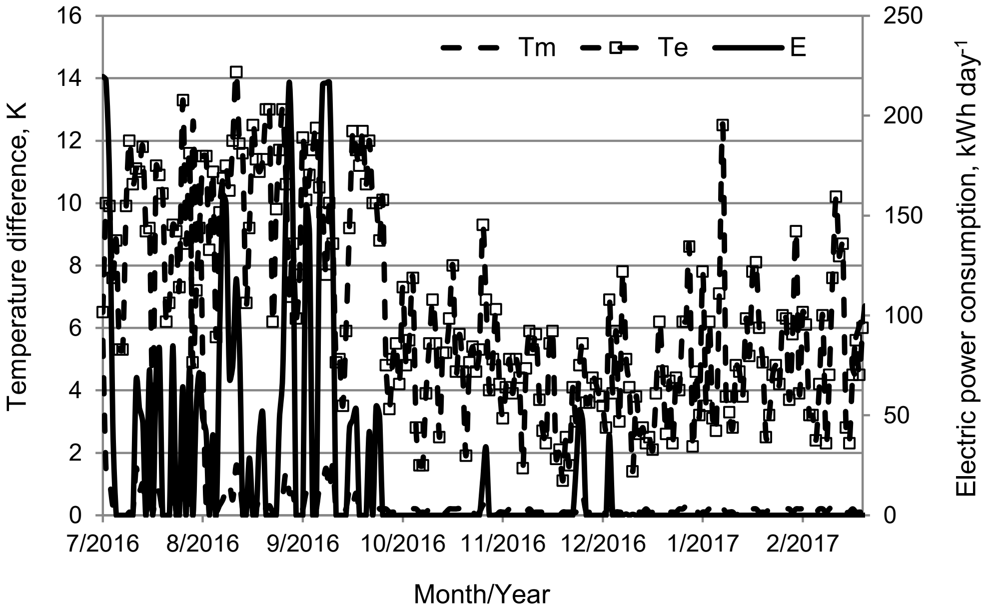

Figure 5. Daily temperature difference and daily electric power consumption for aeration.

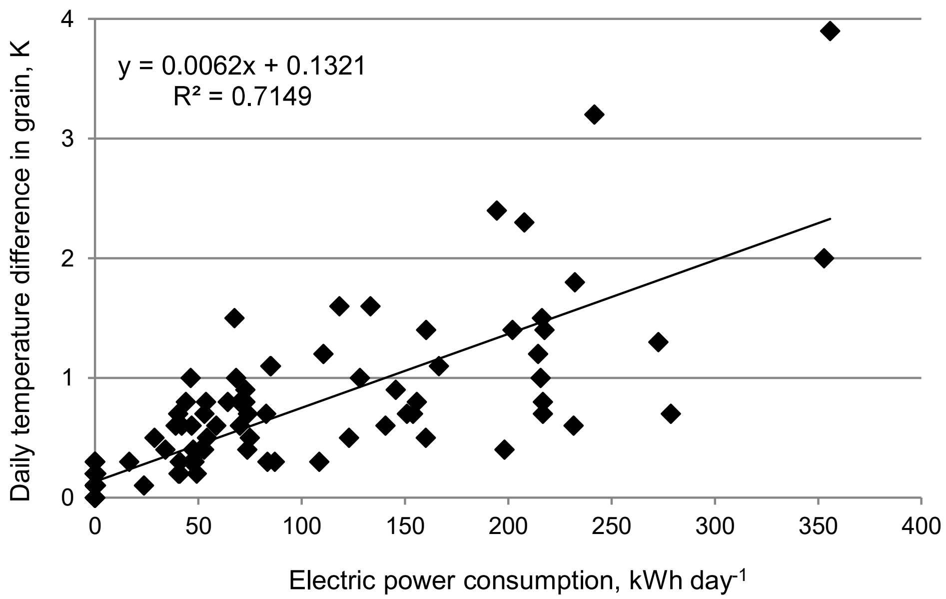

Figure 6. The effect of daily electric power consumption of aeration on daily temperature difference in the malting barley layer.

The daily fluctuations in the temperature inside the stored material in dependence on the consumed energy for aeration are shown in Fig. 6. The linear regression model shows a very strong dependence (r = 0.8455) of daily temperature fluctuations on the consumption of electricity for aeration. Dependence of the average daily temperature inside the grain on outside temperature is shown in Fig. 7. The monitored storage space shows good ability to maintain the required climate in unfavourable outdoor climatic conditions compared, for example, to tower silos due to the capacity and insulation capabilities. Fig. 7 shows a simple linear regression model of the temperature dependence of the stored material inside the store at the outside temperature. This dependence is determined by the thermal insulation properties of the perimeter shell of the warehouse, the use of aeration technology as well as the storage capacity. The correlation coefficient 0.6898 shows strong dependence in the long-term data from entire storage season. During the first 4 months after harvest when grain stabilization by active aeration are used, this dependence is only very weak (r = 0.2208).

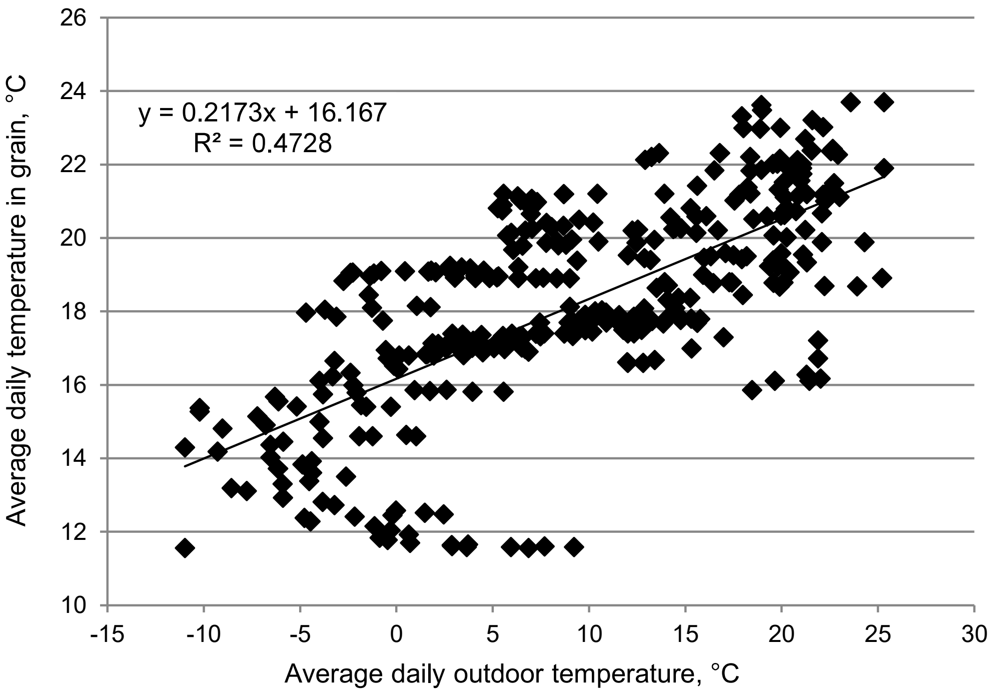

Figure 7. The effect of average daily outdoor temperature on average daily temperature in the malting barley layer.

Generally, in storage halls thanks to storing more grain and to characteristics of storage halls, the trends will be as shown in Figs 2 and 3, Tables 1–3, where the temperature fluctuations within the stored material (air between grains) are not significant and the temperature only copies the general trend from outside temperature, respectively the indoor environment of the warehouse. The temperature inside the material reacts less sensitively to the temperature fluctuations of the external environment due to the good insulation properties of the hall warehouse.

It is also important to note that the temperature difference between the one measured in material layer and inside ambient temperature should be less than 5 °C, as is shown in Fig. 4 at the beginning two months of storage season. Alabadan (2006) reported that the ambient temperatures during the dry season were higher than the wet season. Lawrence et al. (2013) found that the grain surface temperature within a silo was higher than the ambient by 5 °C, which is in agreement with the results herein. Similarly, Lawrence & Maier (2012) reported a difference of 4 °C between different configurations of a silo for maize storage.

Fig. 4 and Fig. 5 indicate that the temperature inside the barley were still higher when the ambient temperature began to decrease in September. The high temperature can cause the stored grains to spoil. The higher temperatures above the grain surface might have been influenced by solar radiation between the roofing and surface layer. To avoid this problem it is necessary to use the installed aeration system in autumn months to let the excess heat escape (Laszlo & Adrian, 2009). Zhang et al. (2016) also show similar results in temperature variation in small grain steel silos installed in a storage hall.

CONCLUSIONS

The key to preserving good qualitative parameters in stored malting barley is to achieve and maintain a suitable storage temperature without major temperature fluctuations. The most favourable grain storage temperatures are generally set at 5–10 °C. The temperature 25 °C should not be exceeded over a long period of time, therefore it is essential to aerate the storage of the commodity immediately after the harvest. The results of the monitoring show a very strong dependence of temperature changes during the day in the barley on the consumption of electricity for aeration. Moreover, the long-term dependence of the average daily average temperature inside the barley on the average daily outside temperature has been demonstrated, but this dependence is significantly lower than in conventional tower silos due to the thermal insulation properties of the perimeter shell, the aeration system used and the capacity of the stored material. Moreover, the results show that this dependence is very weak during the first four months after the harvest, when the stored material is being stabilized by active aeration.

Temperature variations within the storage hall over 12 month period in 2 storage seasons have been measured and evaluated. Temperature variations at 2.1 m depth inside the layer of barley grain increased from July through the end of September in comparison with the measured outdoor temperature and in comparison with the rest of the season. This may probably be associated with heat of respiration of the grains together with the accumulated heat gain during the day and long hours of solar radiation. The variation occurring from July to the start of dry season (October) might be responsible for the slight temperature build up in September. This may imply that the storage hall will need aeration to decrease excessive heat build-up that may lead to deterioration of stored grains quality and possible presence of insects, fungi and their products.

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