

Comparison of a 1 t and a 55 t container when storing spelt grain in mild climate of the Czech Republic

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Abstract. Maintaining a suitable microclimate inside the storage space is the most significant factor in maintaining good quality of stored grain for small farmers. This article is aimed at evaluating the influence of outdoor climatic conditions on the storage conditions, specifically the temperature of stored grain in two storage containers. One structure was a 4×6 m cylindrical container (55 t capacity) with a steel wire mesh wall lined with a textile shell. Spelt grain (*Triticum spelta*) was also stored simultaneously at the same location in a fabric intermediate bulk container (FIBC) bag with maximum capacity of 1 t. Neither structure was mechanically aerated. Grain moisture and temperature were monitored during the spring and start of the summer period of the year 2017 because of the biggest differences between the night and day temperatures. For monitoring of the grain microbiological changes samples were taken for laboratory tests during the whole experiment. Grain quality parameters measured during storage included the bulk density, crude protein, falling number, germination, gluten content, sedimentation index and contamination by mycotoxins. Monitored outdoor environment parameters were temperature, dew point and relative humidity. Results showed a strong dependence of the stored material temperature on the outside temperature in the case of FIBC bags (coefficient of determination $R^2 = 0.927$), whereas the dependence was weaker in the larger structure ($R^2 = 0.625$). Mycotoxins monitored during the period were below the detection limit in both cases.

Key words: postharvest preservation, DON, ochratoxin A, grain quality factors, storage conditions, temperature.

INTRODUCTION

During post-harvest treatment and storage, the mechanical properties of individual food grain kernels have many opportunities to be damaged when subjected to stresses after falling from various heights on its traffic route and finally into the storage container. There is a direct correlation between grain damage during post-harvest treatment and transport, i.e. the content of grain fragments, and the time the cereal can be safely stored (Bradna et al., 2018). A question is also the quantification of changes in some qualitative parameters such as germination during storage. There have been statistically significant

correlations between some physical parameters and mycotoxins (Capouchová et al., 2009).

Grain moisture and storage temperature are the basic parameters in maintaining the correct microclimate throughout the storage period. According to Hammami et al. (2017), high moisture content in food wheat affects increased respiration rate due to enzymatic activity and also faster development of moulds and their products (mycotoxins). These negative factors have a significant influence on the final quality of the grain at the end of the storage period and, therefore, on the final market potential and price of each material lot (Hammami et al., 2017). The moisture content of spelt wheat for storage is not bound by Czech legislation. Based on the legal framework for further processing of grains for food purposes (Czech Decree No. 333/1997 Sb.) and for seed purposes (Czech Decree No. 129/2012 Sb.), the maximum value of grain moisture can be set at 15% wt. The same value was also reported by Zuk-Gołaszewska et al. (2018).

Active aeration during storage is among the gentlest methods for maintaining the required grain quality during storage. It has been found that the efficiency in air distribution is significantly affected by positioning of the air inlets in relation to the container shape. A positive effect has been shown in increasing the area of an aerated base versus increasing the air pressure through a smaller area (Katchatourian & Binelo, 2008). Aerated grain in large containers or indoor warehouses should not be considered as homogeneous material. The degree of permeability in a layer and the pressure gradient are dependent on the vertical position in the material as well as the layer height (Bradna et al., 2018).

Using mathematical modelling of heat transfer in steel silos showed that the temperature of the grain is influenced by the wall temperature, the height of grain layer and the distance between the grain and the wall. The effect of wall temperature on temperature distribution in silos is significant (Ledao et al., 2016) and, according to Foura-Belaifa et al. (2011) the seed germination is highly dependent on storage time.

It is possible to use a wide range of technologies for post-harvest grain treatment. One of them is the use of infrared radiation. When using infrared radiation to dry maize grains, a reduction in microbial load was demonstrated at a certain intensity and duration of action. Thus, the growth of moulds was prevented with a consideration to minimal energy consumption (Wilson et al., 2017). Among others, the quality of grain is also affected by insect contamination, resulting in increased temperature and moisture of the stored commodity (e.g. food wheat) (Four-Belaif et al., 2011). In contrast, Afzal et al. (2017) admitted that, when stored in big bags in subtropical areas, insects may help preserve lower grain moisture in summer and autumn months. The storage of stabilized grain in hermetically sealed plastic bags has proven to be successful because the process of breathing consumes oxygen and produces carbon dioxide, thereby fostering a suitable environment for preserving grain quality. These storage conditions depend not only on the type of grain, stored temperature and humidity, but also on the permeability of the plastic bag and its location in the storage area (Arias, et al. 2013).

MATERIALS AND METHODS

The impact of outdoor conditions on the microclimate inside a tower fabric silo was monitored on a farm in the South Moravian Region of the Czech Republic (geographic coordinates 49.041598, 16.862273). The container was a cylindrical tower made of steel

wire net with a diameter of 4 m and a height of 6 m. The steel net was lined with a textile layer of woven polypropylene fabric with areal weight 200 g m⁻² which enabled passive aeration. This type of container is used most frequently for spelt grain. In the period under review (2017), 55 tons of spelt were stored in the silo. For comparison, another sample with the same spelt variety was stored in a flexible intermediate bulk container (FIBC) bag with flat bottom, open top and equipped with 4 rigid polypropylene handles for manipulation. The physical size of the bag was 90×90×110 cm, complying with the standard ČSN EN ISO 21898. The bag was located in the attic space of a former dairy cow stall, which now serves as a storage area for bedding material and feed. This type of storage bag was made of the same properties of the textile as the silo liner for comparison. Spelt has been deliberately chosen for its good thermal insulation properties and low moisture at harvest. Stabilized grain with 12.3% moisture was used.



Figure 1. The storage of spelt grain in a FIBC bag (on the left) and in a tower silo with steel wire construction and textile liner (on the right).

Platinum temperature sensors were installed in both structures to measure the temperature inside the grain layer, in the centre of the container at a depth of 1 m below surface and connected to a datalogger (Comet S3631) for long-term measurement and recording. In both cases, the datalogger was placed within the indoor storage area to monitor the space above the stored material at a height of 2 m. A Comet S3120 datalogger was installed outside on the north side of the storage building to measure the ambient temperature and relative humidity of the outdoor environment in the immediate vicinity of the warehouse. The recording interval was set to 15 minutes. Data was continuously downloaded to a computer and processed using database tools. Statistical dependence of selected parameters was evaluated using a linear regression model.

The measured quantities were:

t_e – outside air temperature; Δt_e – daily difference of maximum and minimum of outside air temperature; t_{m1} – air temperature between the stored spelt wheat grain in the tower silo; Δt_{m1} – daily difference of air temperature maximum and minimum between the

stored spelt wheat grain in the tower silo; t_{m2} – air temperature between the stored spelt wheat grain in the FIBC bag; Δt_{m2} – daily difference of air temperature maximum and minimum between the stored spelt wheat grain in the FIBC bag.

Technical data of thermo-hygrometers used: Comet R3120, S3120, S3631: temperature measuring range -30 to 70 °C, accuracy ± 0.4 °C.

Qualitative parameters of spelt samples taken from both storage areas were determined according to standardized procedures. Moisture was determined according to ISO 712:2009. Bulk density (BD) was determined according to ISO 7971-3:2009 standard using a quarter-litre measuring container. Falling number (FN) was determined according to ISO 3093:2009 using a Perten LM 3120 mill and 7 g of meal on a 15% moisture basis. Zeleny sedimentation index (SEDI) was determined according to ISO 5529:2007 using a Brabender Sedimat mill. Wet gluten content (WG) content and gluten index (GI) were determined according to the ICC Standard No. 155. Crude protein content (CPC; $N \times 5.7$) was determined by the Dumas method according to ICC Standard No. 167 using a LECO FP-528 analyser and LECO TruMac CNS. Deoxynivalenol (DON) was analysed by the ELISA method using R-Biopharm AG kits (Darmstadt, Germany), according to the manufacturer's instructions. Ochratoxin A (OTA) concentration was determined by high-performance liquid chromatography using Shimadzu Prominence HPLC equipped with Shimadzu fluorescence detector RF-10 AXL.

RESULTS AND DISCUSSION

Summaries of the average monthly outdoor temperature, average material temperature (air between grain) in the tower silo and FIBC bag and average daily temperature differences for each month are shown in Table 1.

At two-month intervals, samples of spelt from the 2016 harvest stored in the silo and in FIBC bag were taken to determine the quality parameters and contents of DON and OTA mycotoxins. The spelt had standard quality (moisture, temperature, BD, FN, CP, etc.) at the time of loading. The moisture of the samples changed during the year depending on the ambient air humidity. An increasing trend of CP content was observed during storage, respectively an increasing trend of nitrogen content ($r = 0.95$, $R^2 = 0.9025$). Dependence on

Table 1. Monthly average values of the observed temperatures and temperature differences during a day

Month	t_e °C	Δt_e °C	t_{m1} °C	Δt_{m1} °C	t_{m2} °C	Δt_{m2} °C
January ¹⁾	-4.9	4.3	3.4	0.1	-3.2	0.6
February	1.5	6.3	1.5	0.1	0.6	0.8
March	8.1	10.2	2.3	0.1	6.9	1.1
April	9.6	9.8	7.7	0.1	9.2	1.1
May	17.3	13.6	11.0	0.2	15.1	1.5
June ²⁾	21.4	15.7	16.7	0.3	20.3	1.5
Total ³⁾	9.4	10.2	6.5	0.1	8.4	1.1

1) January 22nd – January 31st; 2) June 6th – June 13th;

3) January 22nd – June 13th.

storage time and storage container was not apparent in other quality parameters. The content of mycotoxins monitored (DON, OTA) was in all cases always below the detection limit of $20 \mu\text{g kg}^{-1}$ and $0.2 \mu\text{g kg}^{-1}$, respectively. The average values of the monitored parameters, minimum and maximum are shown in Table 2.

Table 2. Qualitative parameters of spelt stored in the FIBC bag and tower silo. Values are averages from 20 samples taken in 2017 and the minimum and maximum values achieved

Parameter	unit	FIBC bag	tower silo
Moisture content	%	12.3 (11.1–16.2)	11.5 (10.9–13.8)
DON	$\mu\text{g kg}^{-1}$	< 20	< 20
OTA	$\mu\text{g kg}^{-1}$	< 0.2	< 0.2
BD	kg hL^{-1}	76.1 (75.3–77.3)	75.6 (74.8–76.4)
FN	s	289 (281–303)	284 (275–298)
SEDI	mL	15 (14–16)	16 (15–17)
GI		20 (18–26)	21 (19–26)
WG	%	33.2 (30.4–34.4)	39.9 (37.4–41.0)
CPC	%	13.2 (12.8–13.5)	13.5 (13.2–14.0)
Germination	%	85.6 (81.0–88.0)	84.9 (81.5–87.0)

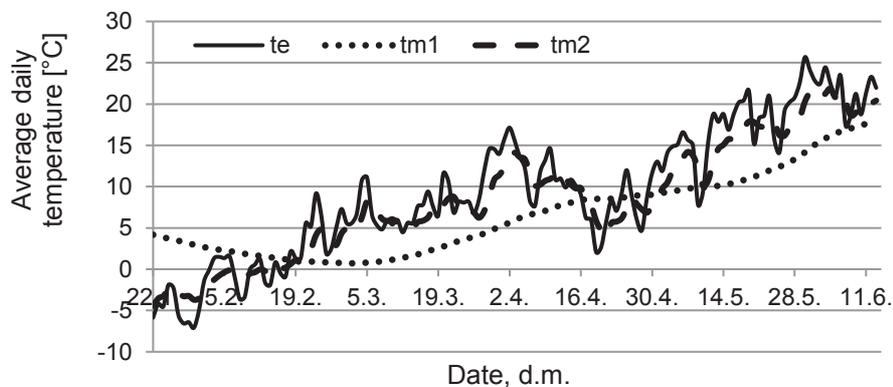


Figure 2. Comparison of the average daily outdoor temperature and average daily temperature in the spelt layer of both storage structures in 2017.

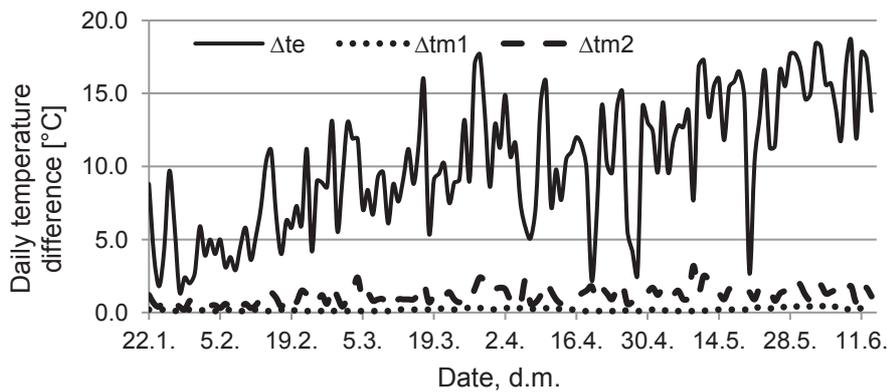


Figure 3. Comparison of the average daily outdoor temperature differences and average daily temperature differences in the spelt layer of both storage structures in 2017.

The trends in temperatures and temperature differences are shown in Table 1 and Figs 2 and 3. Generally, due to the larger amount of material and the thermal insulating characteristics of the warehouse where the silo was located, daily temperature variations

in the material layer in the silo were less than 0.5 °C and the average daily temperature lags the outdoor environment. The temperature inside the material reacts less sensitively to the temperature fluctuations of the outdoors environment due to the good thermal insulation properties of the grain and warehouse.

On the other hand, in the FIBC bag the temperature inside the material responded very quickly to fluctuations in outside temperature, due to both lower volume of stored material and the location of the bag which was an attic space without any roof insulation, i.e. worse thermal insulation properties of the storage space. This experiment site was chosen deliberately to store a smaller amount of the same material than the tower silo, and to verify the effect of extreme storage conditions on the material and the rate of mould and mycotoxin development in such an environment.

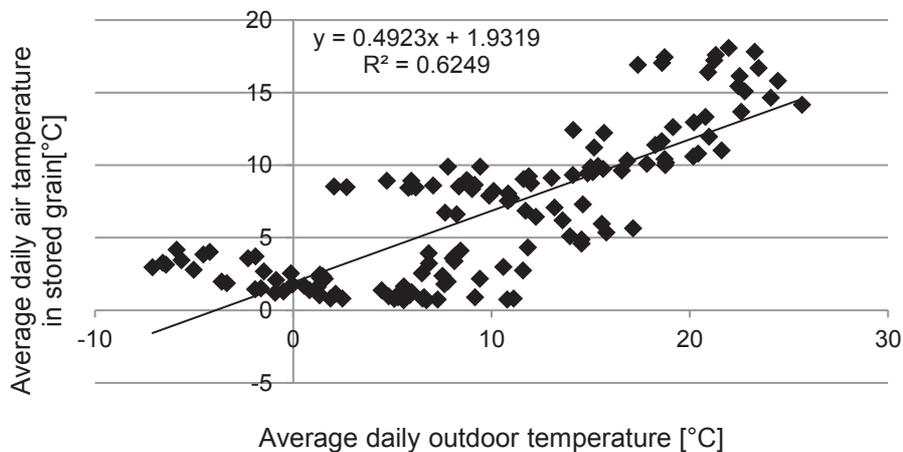


Figure 4. Comparison of the average daily outdoor temperature and average daily temperature in the spelt layer in the silo in 2017.

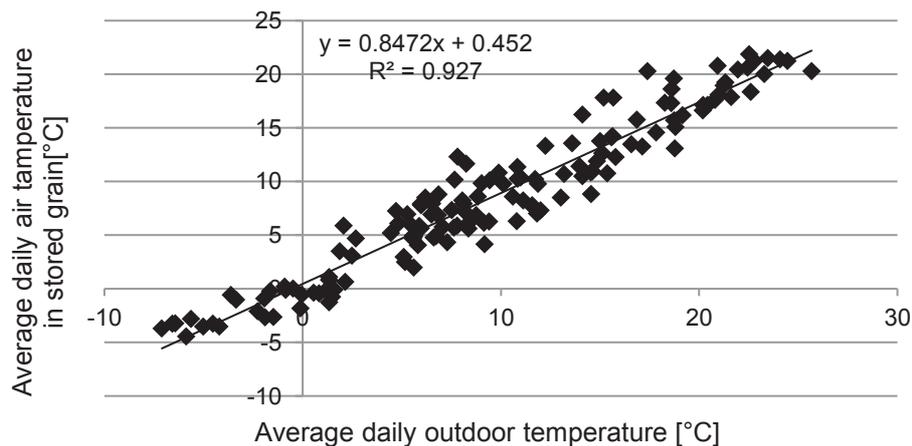


Figure 5. Comparison of the average daily outdoor temperature and average daily temperature in the spelt layer in the bag in 2017.

Dependence of the average daily temperature in the layer of the stored spelt grain on outside temperature is shown in Figs 4 and 5. Fig. 4 shows a simple linear regression model of the temperature dependence of the stored material inside the tower silo on the outside temperature. The correlation coefficient $r = 0.7905$ ($R^2 = 0.625$) shows moderate dependence in the long-term data from the observed part of the storage season. Fig. 5 shows a simple linear regression model of the temperature dependence of the stored material inside the FIBC bag on outside temperature. The correlation coefficient $r = 0.9628$ ($R^2 = 0.927$) shows almost linear correlation and a strong dependence in the long-term data from the observed part of the storage season.

CONCLUSIONS

The results show a strong dependence of the stored material temperature on the outside temperature in the case of FIBC bags (coefficient of determination $R^2 = 0.927$). The dependence in the case of silo storage was weaker ($R^2 = 0.625$). This difference is mainly due to the volume of material stored and the associated heat capacity and thermal inertia. The biological activity of the stored grains may also impact the dependence of the temperature of grains on relative humidity and grain moisture.

There was no significant change in quality parameters during the two-year storage period. Only increasing crude protein content was found. Due to the storage of healthy and cleaned spelt, the storage time in the bag and silo did not affect the content of mycotoxins, which remained below the detection limit. However, significant fluctuations in humidity and temperature of the environment can affect the mycotoxicological quality of the stored production and there is a risk of increasing the content of mycotoxins, especially when storing contaminated, uncleaned grain.

Temperature variations within the silo in the warehouse and in bags placed in an attic storage area directly under roof without any thermal insulation over six-month period have been measured and evaluated. Temperature at 1 m depth inside the layer of spelt wheat grain increased from January through June in comparison with the measured ambient temperature. This may be associated with heat of respiration of the grain together with the accumulated heat gain during daylight hours.

The use of FIBC bags is not ideal for the goal of achieving and maintaining a stable storage temperature. Especially when bags are placed in uninsulated spaces. In such cases, the microclimate inside the bag is greatly affected. Regarding their ability to maintain a stable microclimate, bags were the worse of the two storage technologies used in this study. This was due to the lower storage capacity and thus the lower capacity to accumulate and maintain heat. The solution could be simply storing bags in a warehouse with a sufficient thermal insulation, or even in combination with a microclimate control system.

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REFERENCES

- Afzal, I., Bakhtavar, M.A., Ishfaq, M., Sagheer, M. & Baributsa, D. 2017. Maintaining dryness during storage contributes to higher maize seed quality. *Journal of Stored Products Research* **72**, 49–53. <https://doi.org/10.1016/j.jspr.2017.04.001>
- Arias Barreto, A., Abalone, R., Gastón, A. & Bartosik, R. 2013. Analysis of storage conditions of a wheat silo-bag for different weather conditions by computer simulation. *Biosystems Engineering* **116**(4), 497–508. <https://doi.org/10.1016/j.biosystemseng.2013.10.012>
- Bradna, J., Šimon, J., Hájek, D. & Vejchar, D. 2018. The impact of weather conditions on microclimate in storage facilities. *Agronomy Research* **16**(4), 1580-1589. ISSN 1406-894X
- Capouchová, I., Papoušková, L., Hajšlová, J., Prokinová, E., Kostelanská, M., Škeříková, A., Dvořáček, V., Pazderů, K. & Faměra, O. 2009. Risks of the occurrence of fusarium sp. for baking quality of wheat (Rizika výskytu fuzarióz pro pekařskou jakost pšenice) *Úroda* **12**, 521–526.
- Czech Republic Government Decree Act No. 333/1997 Sb. of 12 December 1997. 1997. Collection of Laws of the Czech Republic. 111. 6786–6809.
- Czech Republic Government Decree Act No. 129/2012 Sb. of 4 April 2012. 2012. Collection of Laws of the Czech Republic. 48.1962–2201.
- ČSN EN ISO 21898 (2006). Packaging - Flexible intermediate bulk containers (FIBCs) for non-dangerous goods (Obaly - Flexibilní středně objemové vaky (FIBC) pro jiné než nebezpečné věci). Prague: Czech Standards Institute.
- Fourar-Belaifa, R., Fleurat-Lessard, F. & Bouznad, Z. 2011. A systemic approach to qualitative changes in the stored-wheat ecosystem: Prediction of deterioration risks in unsafe storage conditions in relation to relative humidity level, infestation by *Sitophilus oryzae* (L.), and wheat variety. *Journal of Stored Products Research* **47**(1), 48–61.
- Hammami, F., Ben Mabrouk, S. & Mami, A. 2017. Numerical investigation of low relative humidity aeration impact on the moisture content of stored wheat. *International Journal of Modeling, Simulation, and Scientific Computing* **8**(2), 1740002.
- Khatchatourian, O.A. & Binelo, M.O. 2008. Simulation of three-dimensional airflow in grain storage bins. *Biosyst. Eng.* **101**(2), 225–238. doi: 10.1016/j.biosystemseng.2008.06.001
- Ledao, Zhang, Xi, C., Hang, L., Wei, P., Zhongjie, Z. & Guangyue, R. 2016. Experiment and simulation research of storage for small grain steel silo. *International Journal of Agricultural and Biological Engineering* **9**(3), 170–178. <https://doi.org/10.3965/IJABE.V9I3.1946>
- Polišenská, I., Pfohl-Leszkowicz, A., Hadjeba, K., Dohnal, V., Jirsa, O., Denešová, O., Ježková, A. & Macharačková, P. 2010. Occurrence of ochratoxin A and citrinin in Czech cereals and comparison of two HPLC methods for ochratoxin A detection. *Food Additives and Contaminants* **27**(11), 1545–1557.
- Wilson, S.A., Okeyo, A.A., Olatunde, G.A. & Atungulu, G.G. 2017. Radiant heat treatments for corn drying and decontamination. *Journal of Food Processing and Preservation* **41**(5), e13193. <https://doi.org/10.1111/jfpp.13193>
- Žuk-Gołaszewska, K., Majewska, K., Tyburski, J. & Gołaszewski, J. 2018. Physical and technological properties of kernels and flour made from spelt grown in an organic farming system in north-eastern Poland. *Journal of Cereal Science* **79**, 501–507. <https://doi.org/10.1016/j.jcs.2018.01.002>