ADVANCED METHODS OF CONTROLLING STORAGE PARAMETERS IN POST-HARVEST GRAIN LINES

Tomáš JEHLIČKA[1], Andrea SMEJTKOVÁ[1], Petr VACULÍK[1]

[1]Department of Technological Equipment of Buildings, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic

Abstract
The aim of this study was to analyse the impact of automation level in aeration control systems on changes in grain quality parameters during storage. The research was conducted in two identical storage facilities. In one, control was performed manually; in the other, an advanced system utilizing artificial intelligence was employed. The dynamics of moisture and temperature reduction in stored bread wheat with an initial moisture content above 16.5% were evaluated. Using the advanced control system, moisture content dropped below 14.5% by the ninth day, whereas under manual control this threshold was reached only by the seventeenth day. A temperature below 20 °C was achieved after 14 days with advanced control, compared to 20 days under manual control. The results confirm that advanced automation enables faster stabilization of grain and reduces storage-related risks.
Keywords: *grain storage, grain aeration, automated aeration control*

INTRODUCTION
Post-harvest grain handling lines are designed to adjust grain quality parameters and provide short-term storage before marketing, particularly by reducing moisture content and regulating the temperature of moist grain (*El-Kholy, Kamel, 2021; Smejtková et al., 2016*). The objective is to decrease the moisture content below 14 % and the temperature below 20 °C throughout the entire volume of stored grain (*Butkovsky, Ilina, 2023*).
From a technological perspective, storage is implemented in vertical silos or horizontal floor storage systems, the latter being preferred in primary agricultural production. Moisture and temperature regulation in floor storage is achieved through aeration, using air supplied via a system of distribution ducts connected to fans (*Zhang et al., 2024; El Melki et al., 2022*). Storage conditions are fundamentally influenced by air parameters - temperature, humidity, and airflow rate per unit of time through the grain layer (*Plumier, Maier, 2021*). Effective operation depends on the control of the aeration system. In practice, various levels of control are used, ranging from simple manual systems to advanced technologies incorporating elements of artificial intelligence (AI) (*Shi, Wang, 2022; Astapenko, Koshekov, 2021*).
Manual or time-based fan switching by the operator remains common, sometimes supplemented with sensor-based monitoring of temperature and moisture within the grain layer (*Myhan et al., 2025*). The most advanced systems use AI-based control that integrates sensor data from both the grain mass and the external environment (e.g., meteorological stations), along with historical data repositories. Based on these inputs, the system can optimize fan operation, minimize energy consumption, and reduce storage losses (*Binelo, Brondani Binelo, 2024*). Although control technologies continue to evolve, their actual impact on grain parameters under operational conditions remains insufficiently documented empirically. A high level of automation contributes to better process organization and reduces operator subjectivity, but may require substantial investment (*Maneghetti et al., 2022*).
The aim of this study is to analyse the influence of different levels of aeration system automation on grain quality parameters during storage under real-world conditions in primary agricultural production. The study compares outcomes achieved with manual control versus advanced AI-based control algorithms.

MATERIALS AND METHODS
The study was conducted in two storage facilities (designated as Facility No. 1 and Facility No. 2).
Both were identical, standardized structures - prefabricated steel halls with fully perforated aeration floors,

each with a storage capacity of 2,000 tons over an area of 1,200 m². Each facility was equipped with eight radial fans rated at 6 kW, connected to an aeration duct system.

The difference between the two facilities lay in the control system used for managing storage conditions. In Facility No. 1, the process was manually controlled by a production operator based on the assessment of grain temperature and moisture. Facility No. 2, following reconstruction, was equipped with an advanced AI-based control system.

Two key parameters were evaluated: the moisture content and temperature of stored grain (common wheat, *Triticum aestivum*), which was initially stored with a moisture content exceeding 16.5%.

In Facility No. 1, monitoring was conducted over a period of three years (2022–2024). The operator manually managed the aeration process based on grain characteristics and time of day. Measurements of moisture and temperature were taken every 48 hours until the moisture content dropped to approximately 14%. Moisture was determined using a Pfeuffer HE 50 operational moisture meter at three randomly selected locations, with the results averaged. Temperature was measured using a Dramiński TROL2 device at a depth of approximately 1 meter.

In Facility No. 2, monitoring was conducted over one year (2024). Aeration control was carried out using a system that integrated moisture and temperature sensors, a weather station (to assess external conditions), data evaluation and prediction models, and a ventilation control unit. Moisture and temperature measurements were conducted in the same manner as in Facility No. 1.

RESULTS AND DISCUSSION

To evaluate the storage parameters under different levels of automation in aeration control systems, changes in grain moisture content and temperature were monitored over time. The measured values of grain moisture and temperature in Facility No. 1 and Facility No. 2 are presented in Table 1.

Figures 1 and 2 illustrate the trends of the monitored parameters. For the manual control system, the data shown are the average values for the years 2022–2024, while for the advanced control system, data from 2024 are presented.

Figure 1 shows the grain moisture values from Table 1 with a fitted trend line. The data indicate that the desired reduction in grain moisture occurs within the first 7–9 days after storage when using the advanced control system. By the 9th day, moisture content drops below 14.5%, a level suitable for long-term storage (*Benhamada, 2024*). In contrast, the manual control system achieved a rapid initial decrease in grain moisture within the first 5 days, followed by a slow and prolonged decline, with moisture hovering around 15%. The threshold of 14.5% was only reached after 17 days - approximately 50% longer compared to the advanced control system. The moisture trend strongly suggests that the use of advanced automation enables a more efficient and faster reduction in grain moisture content (*Astapenko, Koshekov, 2021*).

Figure 2 presents the recorded grain temperature values from Table 1, also with a trend line for clarity. A general requirement for storage is to reduce grain temperature as quickly as possible, thereby slowing metabolic activity and stabilizing the grain (*El-Kholy, Kamel, 2021; Maneghetti et al., 2022*). In the case of the advanced control system, temperature decreased steadily across the grain mass and fell below 20 °C after 14 days. In contrast, with the manual control system, the same temperature threshold was reached only after 20 days - approximately 30% longer. Furthermore, the temperature trend shows that under manual control, grain was exposed to temperatures above 25 °C for the first 14 days.

Tab. 1 Experimental results

Days after storage	Facility No. 1 (Manual Control)								Facility No. 2 (Advanced Control)	
	Year 2022		Year 2023		Year 2024		Avg 2022–2024		Year 2024	
	Moisture [%]	Temperature [°C]	Moisture [%]	Temperature [°C]	Moisture [%]	Temperature [°C]	Moisture [%]	Temperature [°C]	Moisture [%]	Temperature [°C]
1	16,6	29,8	16,8	30,1	16,5	28,2	16,6	29,4	16,9	30
3	16,1	29,7	16,2	29,7	16,1	27,8	16,1	29,1	16,1	27,9
5	15,7	29,7	15,1	29,5	15,8	25,9	15,5	28,4	15,1	25,8
7	15,3	29,6	15,0	29,1	15,5	25,0	15,3	27,9	14,7	24,1
9	15,0	29,5	14,8	28,6	15,3	23,8	15,0	27,3	14,4	22,4
11	14,8	29,0	14,8	27,2	15,2	22,9	14,9	26,4	14,3	21,5
13	14,6	27,2	14,7	26,1	15,1	21,7	14,8	25,0	14,3	19,7
15	14,5	25,3	14,5	24,9	14,9	20,8	14,6	23,7	14,2	18,9
17	14,4	23,1	14,4	21,9	14,7	19,7	14,5	21,6	14,2	18,5
19	14,3	19,5	14,1	20,2	14,3	19,1	14,2	19,6	14,1	18,3
21	14,2	17,6	14,0	18,1	14,2	18,4	14,1	18,0	14,0	18,3
23	14,1	17,1	13,9	17,3	14,0	17,7	14,1	17,4	14,1	18
25	14,1	17	13,9	17,2	14,1	17,7	14	17,3	14	17,9

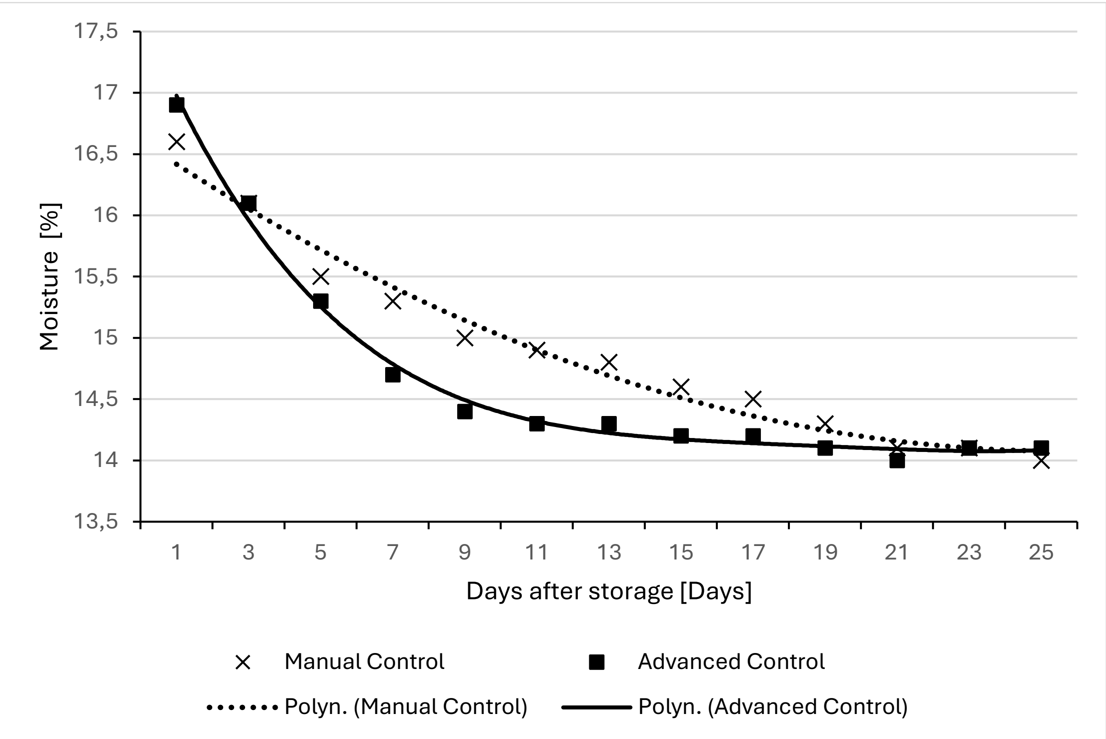

Fig. 1 Course of grain moisture content depending on days after storage

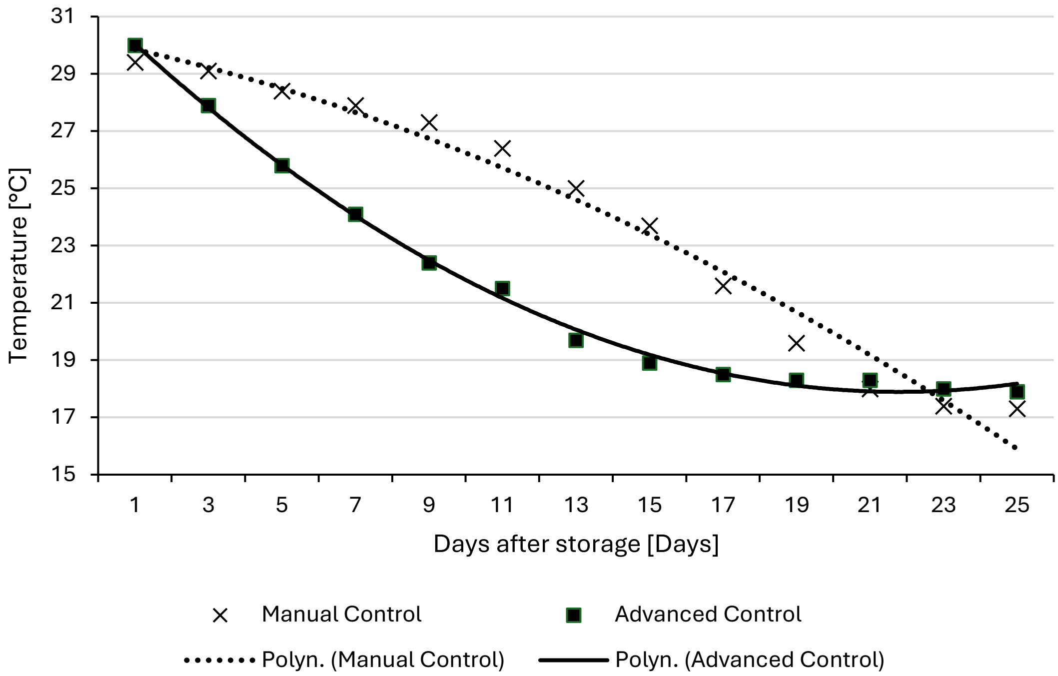

Fig. 2 Course of grain temperature depending on days after storage

CONCLUSIONS

Based on an operational analysis of grain quality parameters (moisture content and temperature) under two aeration control systems with different levels of automation (manual control vs. advanced control using artificial intelligence algorithms), the following conclusions can be drawn: the control system utilizing artificial intelligence algorithms enables optimal grain storage conditions - specifically, achieving target moisture and temperature values - in a significantly shorter time frame (approximately 50% faster moisture reduction and 30% faster temperature reduction). This accelerated stabilization reduces the risks associated with elevated moisture and temperature levels during the post-harvest period.

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Corresponding author:
Ing. Tomáš Jehlička, Ph.D., Department of Technological Equipment of Buildins, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3197, e-mail: jehlickat@tf.czu.cz

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