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APPLICATION OF COOLING IN POSTHARVEST HANDLING OF GRAIN

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Abstract: The present paper addresses the issue of postharvest handling of grain with focus on storage, when cooling is used in order to maintain the quality of the processed product and the required storage period. The paper presents the results of the control measurements at postharvest equipment, their evaluation and comparison. The measurements were performed manually by the means of the measuring device Dickey - John type GAC 2100. Results of the measurements of temperature and moisture content of grain provide basis for decisions upon possible extension of the storage period, alternatively upon further processing of grain. The paper also describes methods of maintaining the required parameters during grain storage, such as cold preservation. This section includes description and operating principle of the device Granifrigor; the recommended storage periods of different types of crops, depending on moisture content and temperature of cooling of grain. Moreover, principles of grain storage are described with respect to division according to moisture content.

Key words: *grain, control measurement, cold preservation, agriculture*

INTRODUCTION

Grain is one of the most important staple foods. It is planted and harvested with great care. According to the Food and Agriculture Organisation of the United Nations

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(FAO), more than 20% of the world's harvested grain is spoiled every year. The major part of this loss is caused by insects and mould activity.

Postharvest handling of grain is essential for reduction of moisture content to proper storage value of 13-14%. In storage conditions incompatible with the prescribed moisture content occurs deterioration of grain, for example mashing, moulds etc. Determination of mass of dry matter for calculation of moisture content dry basis and moisture content wet basis should be carried out in accordance with the standards for particular materials. Various devices operating with different electrical properties of tested materials are used to measure moisture content of agricultural materials. Identification of moisture content follows the procedure established by the producer.

Since grain is an organism, metabolic process of respiration is present. Intensity of respiration is influenced particularly by grain moisture content, temperature and amount of surrounding air. Grain constantly respires and under certain conditions it "comes to life". Therefore it is necessary to monitor several parameters, such as temperature, moisture content, changes of colour, odour development, pest infestation etc. When the moisture content increases, water from the process of respiration accumulates and supports further metabolic processes. Generated heat contributes to even more intense respiration and may eventually damage sensory and physiological properties of grain or spontaneous combustion may occur [1].

The paper is focused on the issue of maintaining the required parameters during grain storage. This practice is of great importance in terms of the period and quality of grain storage depending on grain moisture content [2].

MATERIAL AND METHODS

Water is fundamental to all life processes of organisms. It exists on their surface, in capillaries and inside the cells of their particular components as well. Reduction of water content is vital for long-term preservation of the material, because it generates conditions which inhibit biological activity. Moisture is the carrier of metabolism, i.e. chemical response of organisms to their environments. At the same time it is necessary to consider maintaining of utility of grain. More specifically, it means maintaining of germination of seed corn, maintaining of certain kinds of proteins, carbohydrates, fats, vitamins and ferments, which determine quality of the particular material or enhance properties relevant for further processing as food, forage or in the industry. Therefore knowledge and precise determination of moisture content of the material is of considerable importance [3].

Determination of mass of dry matter (M_{MS}) for calculation of moisture content dry basis and moisture content wet basis should follow the standards for the materials in question. If such standard does not exist yet, the sample of the material is dried in laboratory dryer at temperature exceeding the atmospheric boiling point of removed moisture (e.g. water at 105°C). Mass loss of the sample is examined in half hour intervals. Mass of dry matter is identified as mass of the sample which remains constant during further drying.

Moisture content of agricultural materials can be measured by various devices operating on the principle of different electrical properties of tested materials. Measurements follow the procedure established by the producer. When determining moisture content of crops outside the measuring range of the device or when using difficult-to-grind samples, it is possible to adhere to the following instructions: the amount of test sample with higher moisture content is mixed with a sample of the same weight with known lower moisture content. The mixture is thoroughly stirred and used for measurements. Moisture content of the sample is calculated according to the relation [4]:

$$w = 2w_1 - w_2 \tag{1}$$

where:
w [%] - moisture content of the sample,
w_1 [%] - measured moisture content of the mixture,
w_2 [%] - moisture of the sample with known lower moisture.

Moisture content of the dried materials is presented in accordance with the valid standard as moisture content dry basis and moisture content wet basis [5,6]:

$$u = \frac{M_V}{M_{MS}} = \frac{M_M - M_{MS}}{M_{MS}} \tag{2}$$

$$w = \frac{M_V}{M_M}100 = \frac{M_M - M_{MS}}{M_M}100 \tag{3}$$

where:
u [kg.kg^{-1}] - moisture content dry basis,
w [%] - moisture content dry basis,
M_V [kg] - mass of moisture,
M_M [kg] - mass of moist material,
M_{MS}[kg] - mass of dry matter.

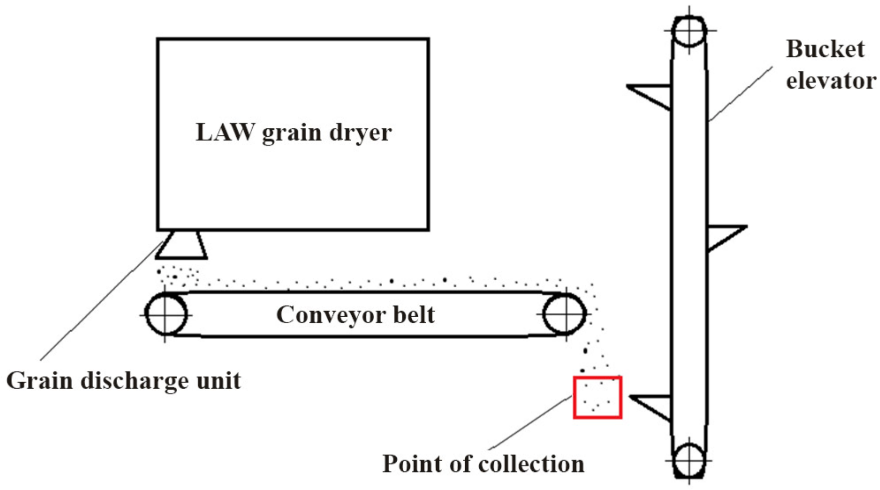

Figure 1. Scheme of point of grain sample collection

Control measurement at postharvest machinery is performed by the means of manual device Dickey - John type GAC 2100 for measuring of grain moisture content. The results obtained from the same hygrometer may be influenced by different conditions during cultivation, maturation and also by moisture content, temperature, harvest, transport and dirt content, especially regarding grains with high moisture content. Methods of calibration checking of grain hygrometers are established by the Slovak Technical Standard STN ISO 7700-1 [7].

AC 2100 is a reliable device designed for immediate determination of moisture content, temperature and bulk density for 64 different crops [3].

It operates on the following principle of analysis:

- filling of the chamber with grain,
- automatic weighing,
- automatic temperature correction,
- automatic bulk density compensation,
- emptying of the chamber.

Main parameters:

- measured quantities: moisture content, temperature and bulk density,
- moisture range: 5 to 45% (depending on calibration curve of the crop),
- crop temperature: 0 ° - 50 °C,
- temperature difference: 20 °C (room to grain sample),
- sample size: approximately 250 grains

Cold preservation by means of cooling device Granifrigor KK 220

The advantage of cold preservation is particularly risk-free storage without quality loss even in big warehouses. Low temperatures of grain provide reliable protection against insect infestation and their reproduction. As a result, potential costs of expensive chemical treatment and gassing are avoided [8].

Cool, dust-proof spot protected from the weather is suitable for installation. The distribution box should be during warm summer days located in the shadowy side of the building.

Parameters:

- cooling performance in 24 hours (220- 350 $t \cdot day^{-1}$)
- chilled air fan: volume flow at back pressure 1000 Pa (5700 $m^3 \cdot h^{-1}$)
  2000 Pa (4900 $m^3 \cdot h^{-1}$)
  3000 Pa (3500 $m^3 \cdot h^{-1}$)
- refrigerating capacity compressor (31,3 kW)
- average output (26,0 kW)
- electrical connection (63 A)
- diameter of connection cold air hose (300 mm)
- condensation water runoff average (16 $l \cdot h^{-1}$)
- weight (850 kg)

The fan of the Granifrigor grain cooler draws in the ambient air. This air is simultaneously cooled by an air conditioner (evaporator) to the desired temperature and dehumidified while moisture is being removed. The Hygrotherm unit then warms the cold air again, thereby lowering relative humidity. The Hygrotherm unit uses energy from the cooling circuit for heating. Therefore additional energy costs are effectively prevented. Cooled and dried air is fed through the air distribution of the warehouse and is forced through the grain. This system is suitable for use both in warehouses and tower silos. Eventually, the air is released outside through the exhaust vents while it extracts heat and moisture absorbed from the grain [3].

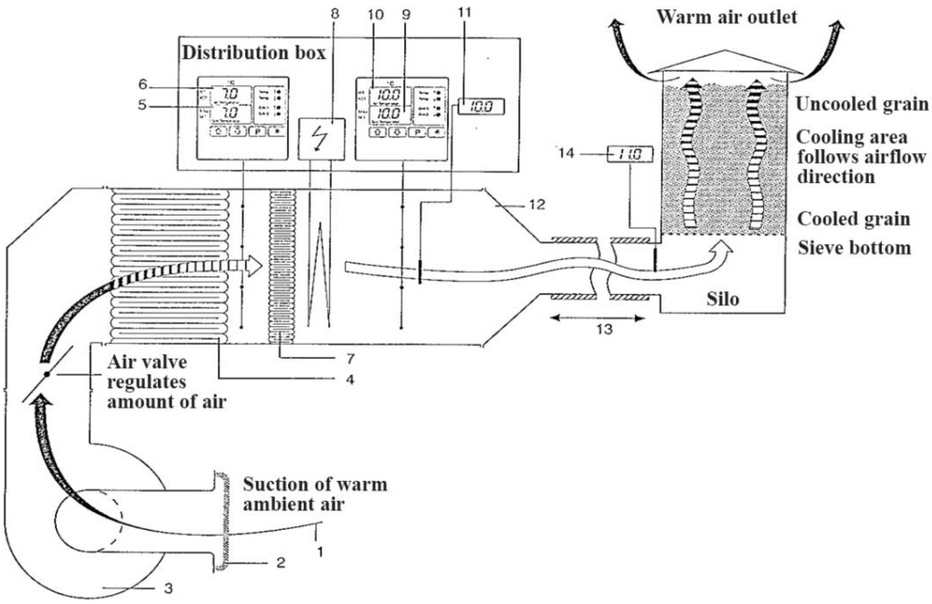

Figure 2. Scheme of air treatment by the device Granifrigor

1- air inlet, 2- dust filter, 3- centrifugal cool air fan, 4- cooling system, 5- controller of cooling air temperature, 6 - indicator of temperature after the cooling system, 7- Hygrotherm unit (for warming and drying of cooling air), 8 - electric heating register, 9 - controller for further heating, 10 - temperature controller for outlet temperature, 11- temperature indicator for outlet temperature, 12- cold air outlet from Granifrigor, 13 - channel of cooling air into the silo; in this area occurs further heating of the cool air by heat transfer, 14- recommended thermometer for cooling air temperature at silo inlet.

Before interruption of cooling, it is important to observe the cooling temperature in order to avoid interaction of warm air with cooler grain once the cooling process is restarted. Regular temperature monitoring in warehouses is crucial for early detection of changes and prevention of damage from overheating.

Average temperature at which development of insects ceases is +15 °C or lower. Growth of microbes and moulds is significantly inhibited by cooling. Whereas growth of woodworm stops at 5 °C, fundamental factor in its life cycle is moisture. Grain infested by woodworm should be definitely more dried and repeatedly cooled.

Principles of grain storage:

- dry grain (moisture content 12 – 15%): warm parts which should be stored for more than 3 months are considerably cooled in order to avoid self-heating and insects. Areas infested with insects should be always cooled as quickly as possible to prevent their further spreading to other warehouses. Storage temperature: ca. 13 – 16 °C.
- grain with critical moisture content (15,5 – 17%) is no longer dried, only cooled. Storage temperature: ca. 10 – 11 °C.
- moist grain (moisture content up to 22%): cooled grain has long-term storability. Storage temperature: ca. 7 – 8 °C.
- moist grain (moisture content exceeding 25%): large amounts of grain should be partially dried in a dryer, reduction of moisture content may considerably extend the period safe from self-heating. On the other hand, small amounts (approximately corresponding to dryer performance in 24 hours) with very high moisture content- for example maize with moisture content of 30 – 40 % - may be preserved by cooling for several days. Storage temperature: ca. 5 – 6 °C [9].

RESULTS AND DISCUSSION

Control measurement of a grain sample at the postharvest machinery is carried out every hour. The grain sample is collected from a point which is located between a conveyor belt which extracts the material from the grain dryer and a bucket elevator which transports the material for storage or distribution. The weight of the test sample is at least 250 g.

The test sample is poured into the chamber of the measuring device. The device automatically weighs the test sample. The measurement is activated by pressing the appropriate button which enables determination of the particular type of the material. The obtained values of moisture content and temperature of the test sample are then shown on a display. These values are then noted down in the appropriate table „Dryer SBC- operating journal".

In discharge rate 0,6/50, 0,6 is duration of discharging and 50 is duration of the drying cycle.

Table 1. Measured values at the grain postharvest machinery

Date	*Time*	*Temperature [°C]*		*Product moisture content [%]*		*Discharge rate*	*Settings*
		Warm air	*Product*	*Initial*	*Final*		*Fuel nozzle*
4.12.2012	9^{00}	*129,1*	*57,4*	*24,7*	*13,8*	*0,6/50*	*130 °C*
	10^{00}	*128,3*	*56,8*	*24,3*	*13,7*	*0,6/50*	
	11^{00}	*129,1*	*55,8*	*24,7*	*14,0*	*0,6/52*	
	12^{00}	*129,5*	*56,6*	*25,9*	*13,9*	*0,6/50*	
	13^{00}	*129,1*	*55,6*	*31,8*	*14,0*	*0,6/52*	
	14^{00}	*128,1*	*57,3*	*31,0*	*13,8*	*0,6/51*	
	15^{00}	*129,1*	*56,9*	*26,0*	*13,6*	*0,6/51*	
	16^{00}	*127,8*	*56,4*	*24,8*	*14,2*	*0,6/51*	
	17^{00}	*128,1*	*56,2*	*22,8*	*13,9*	*0,6/52*	

If final moisture content does not reach the desired values which are essential for storage without unwanted difficulties, discharge rate may be modified by the following methods:

- increase of the temperature of warm air,
- extension of the drying cycle.

Tab. 2 indicates that the LAW dryer has considerably higher average difference between initial and final moisture content than the B1 – 15 dryer at drying of maize at lower performance when considering analogical amount of maize before drying. Similarly, consumption of both gas and electric energy of the LAW dryer is significantly lower than that of the B1 – 15 dryer.

Table 2. Results of drying for the particular years

Year	*unit*	*2003*	*2004*	*2011*	*2012*
		Dryer type			
		B1-15	*B1-15*	*LAW*	*LAW*
Maize before drying	*[t]*	*9112*	*9029*	*12059*	*9483*
Maize after drying	*[t]*	*8645*	*8393*	*10549*	*85586*
Days of operation	*[d]*	*28*	*31*	*34*	*25*
Hours of operation	*[h]*	*346*	*471*	*694*	*517*
Average operation	*[$h \cdot day^{-1}$]*	*12,3*	*15,1*	*20,4*	*20,7*
Gas consumption	*[1000 m^3]*	*62*	*152*	*166*	*127*
Electric energy consumption for drying	*[1000 kWh]*	*30*	*41*	*45*	*34*
Electric energy consumption for cleaning	*[1000 kWh]*	*26*	*35*	*51*	*40*
Average difference between initial and final moisture content	*[%]*	*3,5*	*7,2*	*8,9*	*8,8*
Average performance	*[$t \cdot h^{-1}$]*	*25*	*17,8*	*15,2*	*16,6*
Average performance	*[$t \cdot h^{-1}$]*	*26,3*	*19,2*	*17,4*	*18,4*
Gas consumption	*[$m^3 \cdot t\%^{-1}$]*	*1,95*	*2,34*	*1,55*	*1,52*
Electric energy consumption	*[$kWh \cdot t\%^{-1}$]*	*0,94*	*0,63*	*0,42*	*0,41*

Results of cold preservation

Sorption isotherms show the equilibrium state between grain moisture content and relative air humidity. Relative humidity of blown cooling air may be higher at cooling of more moist grain than at cooling of dry grain. At moisture content of 15% the grain is cooled to approximately the same temperature as the blown air. When considering very dry areas of grain (8 – 13%), the achievable temperature of grain is substantially higher than the temperature of blown air (3 – 6 °C).

Table 3. Storage period of seed grain and malting barley

Seed grain and malting barley		
Moisture content	*Storage temperature*	*Approx. storage period*
12,0 – 15,0%	*9 – 12 °C*	*long-term storage*
15,0 – 16,5%	*8 – 10 °C*	*1 – 1,5 years*
16,5 – 18,0%	*5 – 7 °C*	*4 – 6 months*
18,0 – 20,0%	*5 °C*	*2 – 3 months*
20,0 – 22,0%	*5 °C*	*3 – 4 weeks*

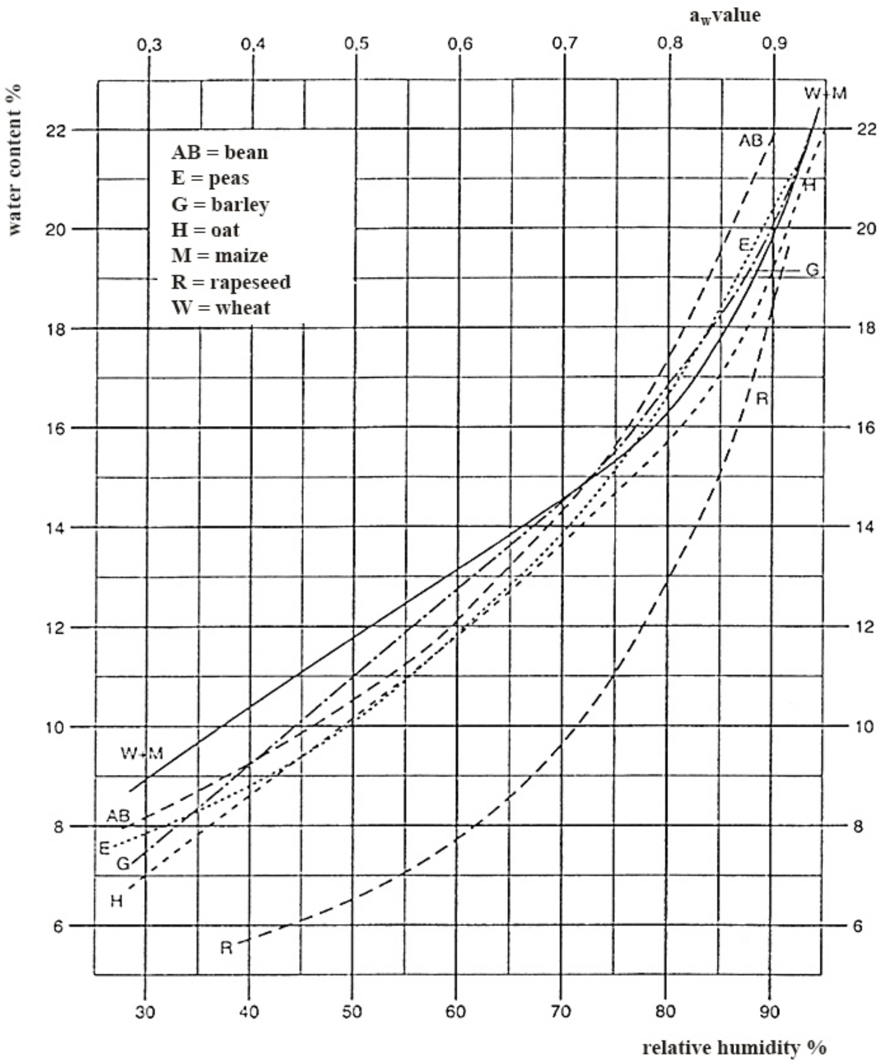

Figure 3. Sorption isotherm of different types of grain

Table 4. Storage period of edible wheat

Edible wheat		
Moisture content	*Storage temperature*	*Approx. storage period*
12,0 – 15,0%	*10 – 22 °C*	*long-term storage*
15,0 – 16,5%	*9 – 10 °C*	*long-term storage*
16,5 – 18,9%	*8 – 10 °C*	*5 – 10 months*
18,0 – 20,0%	*8 – 10 °C*	*2 – 7 months*
20,0 – 22,0%	*6 – 8 °C*	*4 – 16 weeks*

Table 5. Storage period of grain used as forage

Grain used as forage		
Moisture content	*Storage temperature*	*Approx. storage period*
12,0 – 15,0%	*10 – 22°C*	*long-term storage*
15,0 – 16,5%	*9 – 10°C*	*long-term storage*
16,5 – 18,9%	*8 – 10°C*	*6 – 13 months*
18,0 – 20,0%	*8 – 10°C*	*3 – 9 months*
20,0 – 22,0%	*6 - 8°C*	*5 – 20 weeks*

From the tables indicating storability of particular agricultural crops we can see that cooling by the means of the Granifrigor device may be an essential part of long-term storage of grain with various initial moisture contents. Cold preservation enables to maintain the properties of grain which are analogical to the quality prior to storage.

CONCLUSIONS

From the obtained results we may draw the following conclusions. The Granifrigor cooling device from the FrigorTech company is suitable for risk-free long-term storage of grain without quality loss. Other advantages of cooling of grain are protection against insect infestation and development of moulds and mycotoxines as well as minimisation of losses caused by grain respiration. From the economic point of view it is particularly convenient because expensive and unecological chemical treatment is prevented. In addition, costs of grain drying are lower and there is no need to restack the grain. Cooling may be carried out regardless of weather conditions while harvest freshness and germination of grain is maintained. The purchase of Granifrigor cooling device proved to be a long-term profitable investment.

The results of control measurement show that moisture content in every experiment ranged from 12 to 15%. These values are proper for long-term storage of grain. To summarise, the process of postharvest handling of grain in the Močenok farm may be considered as sophisticated in terms of expertise and technology due to modern equipment and qualified personnel.

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PRIMENA HLAĐENJA U POSTUPCIMA SA ZRNOM POSLE ŽETVE

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***Sažetak*:** Ovaj rad se bavi postupcima sa zrnom posle žetve, sa naglaskom na skladištenje, kada se hlađenje koristi da bi se održao kvalitet prerađenog proizvoda i potrebni period skladištenja. U radu su prikazani rezultati kontrolnih merenja na opremi posle žetve, njihova evaluacija i poređenje. Merenja su obavljena ručno, mernim uređajem Dickey - John tipa GAC 2100. Rezultati merenja temperature i sadržaja vlage u zrnu daju osnove za odlučivanje o mogućem produženju perioda skladištenja ili daljim postupcima sa zrnom. U radu su takođe opisane metode održavanja potrebnih parametara tokom skladištenje žita, kao što je hladna zaštita. Ovaj deo uključuje opis i princip rada uređaja Granifrigor, preporučeno vreme za skladištenje različitih vrsta useva, u zavisnosti od sadržaja vlage i temperature hlađenja zrna. Štaviše, principi skladištenja žita su opisani u odnosu na podelu prema sadržaju vlage.

Ključne reči: *zrno, kontrolno merenje, hladna zaštita, poljoprivreda*

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