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Factors Affecting Carbon Dioxide Concentration in Interstitial Air of Wheat Stored in Hermetic Plastic Bags (Silo-bag)

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Abstract: In 2007 about 35 million tonnes of grains were stored in hermetic systems (silo-bags) in Argentina, and about 5 million tonnes of that was wheat. The wheat stored in these silo-bags was mostly used for milling (internal and external market), but also for seeds for the next planting season.

The goal of this research was to conduct a series of field experiments in order to identify the main factors affecting the carbon dioxide (CO_2) and oxygen (O_2) concentrations, as an indicator of biological activity and appropriate wheat storability conditions.

The experiments consisted of monitoring the gas composition of the interstitial air, grain commercial quality, grain moisture content (MC), and grain temperature of several silo-bags.

The main results indicated that the CO_2 concentration of wheat stored in hermetic plastic bags increased with grain MC. At MC below 13% the CO_2 concentration was below 5%, and as mold become active at higher MC the CO_2 concentration increased to 30% for MC of 19%.

Silo-bags with good quality wheat resulted in lower CO_2 concentration than silo-bags with poor quality wheat at the same MC, implying that poor quality wheat had higher biological activity (CO_2 concentration up to 7 percentage points higher).

The effect of average grain temperature on CO_2 concentration became substantial when grain MC was above 14%. For silo-bags with wheat MC higher than 14% the CO_2 concentration was higher during the warm season than during the cold season, and this difference was up to 7 percentage points when wheat MC was between 16% and 17%.

Key words: grain quality, biological activity, modified atmospheres

Introduction

In 2007 about 35 million tonnes of grains were stored in hermetic systems (silo-bags) in Argentina, and about 5 million tonnes of that was wheat. The wheat stored in these silo-bags is mostly used for milling (internal and external market), but also for seeds for the next planting season.

Each silo-bag can hold approximately 200 tonnes of wheat and with the available handling equipment is quite simple to load and unload. These plastic bags are 60 m long, 2.74 m diameter and the plastic cover is made of three layers (white outside and black inside) with 235 micrometers of thickness (Figure 1).

The silo-bags are waterproof and have a certain degree of gas-tightness (oxygen (O_2) and carbon dioxide (CO_2)). As a result, respiration of the biotic components of the grain mass (fungi, insects and grain) increases CO_2

Fig. 1 Picture of a 200 – tonne capacity (60 m long and 2.74 m diameter) hermetic storage plastic bag (silo-bag).

and reduces O_2 concentrations. When the biological activity is intense, the degree of modification of the typical atmospheric gas composition (21% O_2 and 0.033% CO_2) is greater, which would limit grain respiration and mold[1]

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and insect development[2,3]. It has also been also observed that high CO_2 concentration reduced the ability of *Aspergillus flavus* to produce aflatoxin.

Bartosik et al. [4] summarized previous experiences of storing grain in silo-bags, where it was demonstrated that the grain temperature in the hermetically sealed plastic bags followed the pattern of the ambient temperature throughout the year, implying that temperature of the grain mass does not reveal biological activity in the grain mass. The average moisture content (MC) did not significantly change during any storage experiment for both dry and wet silo-bags. In general, no MC stratification was observed in wheat silo-bags. When the grain was stored at the market MC, no significant decrease in the quality parameters could be observed during 150 days of storage. However, when grain was stored above the market MC, the decrease in some of the quality parameter could be observed. The increase in the CO_2 concentration was higher at the end of the storage time and also was higher in those bags with wetter grain (13.0% of CO_2 for 12.5% MC, and 22.8% of CO_2 for 16.4% MC after 100 days of storage). Based on these observations the authors hypothesized that measurement of gas composition in the interstitial air could be used as an indication of the biological activity of the grain mass in the hermetic storage systems, and as a tool for monitoring grain storability. However, a better understanding of typical CO_2 concentrations for wheat silo-bags is required to use this technology for monitoring grain storability.

The CO_2 and O_2 concentration in the silo-bag depends on the balance between respiration (consumption of O_2 and generation of CO_2), the entrance of external O_2 to the system, and the loss of CO_2 to the ambient air (Fig. 2).

The movement of gases in and out of the silo-bags depends on the gas partial pressure differential and the permeability of the system (through openings in the plastic cover, or through the natural permeability of the plastic material to gases). Grain type and condition, MC, temperature, storage time and O_2 and CO_2 concentrations affect the respiration rate. The temperature of the grain depends on the initial grain temperature (this effect is less important as the storage period increases), the sun radiation, the heat release from the respiration process, and the transfer of heat with the air and soil (grain temperature increases during spring and summer and decreases during fall and winter). The grain MC depends on the initial grain MC, the entrance of moisture from the outside (through openings after a rain event into broken or poorly sealed silo-bags), and the moisture released from the respiration process. Additionally, due to the day and night temperature differential, some moisture condensation can occur in the top grain layers resulting in a localized spot of wetter grain.

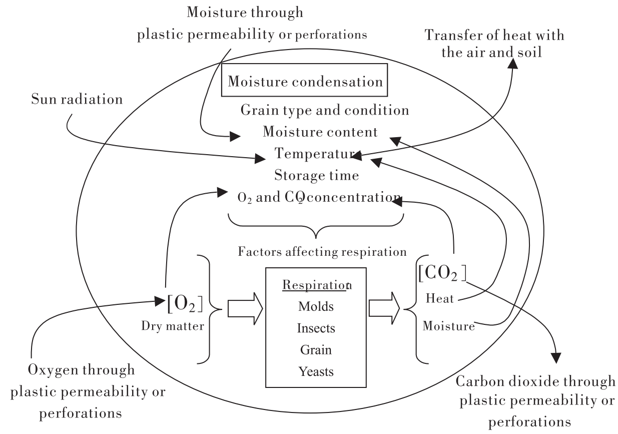

Fig. 2 Diagram of the main factors affecting respiration of grain and microorganisms in the silo-bag, the relationships among them, and the final O_2 and CO_2 concentrations.

Thus, the goal of this research was to study the effect of grain MC, grain temperature and grain quality on CO_2 concentration in silo-bags holding wheat.

Materials and Method

The tests were carried out at grain elevators and on farms in the south east of Buenos Aires province, Argentina, through three storage seasons (from January 2006 to May 2008). Most of the wheat silo-bags were filled in December – January and stored until June or July. However, a small proportion of them were stored for more than one year.

For each silo-bag two sampling locations were established. The procedure consisted of measuring first the gas concentration (O_2 and CO_2) with a portable gas analyzer (PBI Dan Sensor, CheckPoint, Denmark), perforating the plastic cover with a needle. The gas composition was analyzed for three levels in each sampling location, close to the top of the bag, at the middle and close to the bottom.

After the gas composition was analyzed, a wooden stick with three temperature sensors was inserted in the grain mass (diagonally, from the top and side to the bottom and center of the silo-bag) to measure grain temperature at approximately 0.1, 0.7 and 1.4 m from the surface.

In each sampling location grain was collected from three different levels (top = 0.10 m depth, middle = 0.75 m depth, and bottom = 1.6 m depth. Total height of the bag = 1.7 m) using a standard torpedo probe. Material from each one of the three sampling locations was segregated by level (surface, middle, and interior). The grain samples were stored in a hermetic plastic bag and brought to the Grain Postharvest Laboratory of the Balcarce Experimental Station of the National Institute of Agricultural Technologies (INTA). After probing the silo-bags the openings were sealed with a special tape in order to restore the air – tightness.

Additional information of the silo-bag was collected, such us filling and sealing quality, history of openings, perforations due to wild animals or bad sealing after sampling, improper preparation of the soil where the silo-bag was placed (when silo-bags were assembled on top of crop residues it results in perforations of the bottom), silo-bags assembled in low lands with risk of flooding, and any other relevant information.

At the laboratory, grain samples were analyzed for MC (GAC 2100, Dickey – John) and commercial quality according to the Argentina wheat quality standard[5]. Later, each sample was qualified as good quality wheat or poor quality wheat according to Table 1. The monitoring procedure was repeated approximately every 15 days during the entire storage period.

Table 1. Limits of the quality factors of the argentine wheat commercialization standard used to categorize the grain samples as good quality or poor quality.

Grain quality	Quality	Test weight	Foreign matter	Damaged kernel	Broken and vane kernels
Grade		(kg/hL)	(%)	(%)	(%)
Good quality	1	79.0	0.2	1.0	0.50
	2	77.5	0.6	1.5	0.85
Poor quality	2	76.0	0.8	2.0	1.20
	3	73.0	1.5	3.0	2.00
	out of standard				

Results and Discussion

Figure 3 shows the relationship between grain MC and CO_2 concentration. The CO_2 concentration increased with the increase in grain MC, which is a consequence of the biological activity. When the wheat MC was lower than 13% the average CO_2 concentration was below 5% (presumably due to grain respiration). When the wheat MC increased to the point at which molds became active (between 13.5 and 14.5%) the CO_2 concentration increased to 15% with wheat at 16% MC, and to 30% with wheat MC above 19%. The data shown in Figure 2 corresponds to silo-bags without visible structural problems, although some silo-bags with perforations in the bottom side that were not noticed during sampling might be included.

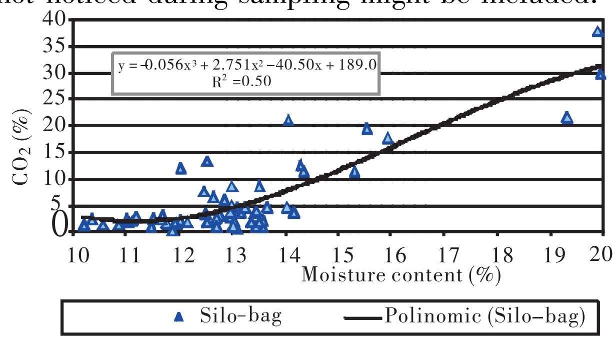

Fig. 3 CO_2 concentration in silo-bags as function of wheat moisture content.

Figure 4 shows the difference in CO_2 concentration of silo-bags with good and poor quality wheat for different grain MCs. Poor quality grain has more percentage of foreign matter, broken kernels and damaged kernels. As a result, for the same MC level, silo-bags holding poor quality wheat resulted in higher CO_2 concentration than silo-bags filled with good quality wheat, due to the higher biological activity of the poor quality wheat. The difference between both grain types increased from about 5 percentage points of CO_2 for 13% MC to 7.5 percentage points for 15.5% wheat MC.

Figure 5 shows the CO_2 concentration for silo-bags sampled during the warm and cold storage season. Storage temperature affects biological activity, reducing the respiration rate of grain and microorganisms. At low grain MC there was almost no difference in CO_2 concentration for the warm and cold season, while for MC above 14.0% (presumably MC at which mold become active) the difference in CO_2 concentration during the warm season (January – March) was up to 7 percentage points higher than during the cold season (May – July).

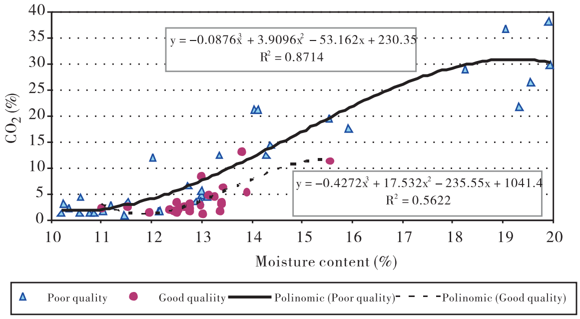

Fig. 4 CO_2 concentration at different grain moisture contents for silo-bags with good and poor wheat quality.

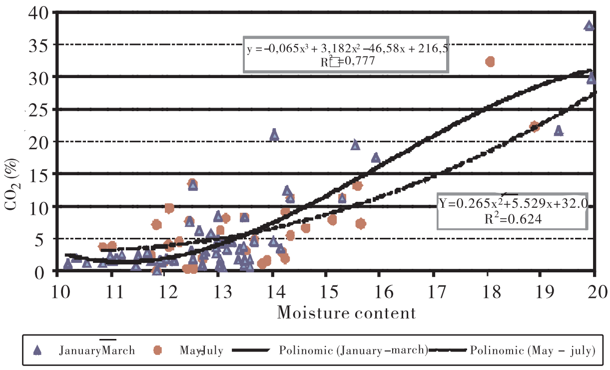

Fig. 5 CO_2 concentration at different grain moisture content for silo-bags sampled during the warm storage season (January – March) and the cold storage season (May – July).

This study showed that the main factor affecting CO_2 concentration in wheat silo-bags was MC, which increased the CO_2 concentration from 5% to 30% when the wheat MC increased from 14% to 19%. Grain quality was less important, although poor quality wheat had from 5 to 7.5 percentage points higher CO_2 concentration than good quality wheat. It was also showed that the effect of quality increased with MC. Finally, the effect of temperature was important for wet wheat (up to 7 percentage points higher), but for wheat below 14% MC the effect of temperature was not noticeable.

Conclusions

The CO_2 concentration of wheat stored in hermetic plastic bags increased with grain MC. At MC below 13% the CO_2 concentration was below 5%, and as mold became active at higher MC the CO_2 concentration increased to 30% for MC of 19%.

Silo-bags with good quality wheat resulted in lower CO_2 concentration than silo-bags with poor quality wheat at the same MC, implying that poor quality wheat had higher biological activity, (CO_2 concentration up to 7 percentage points higher).

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