STORAGE OF CORN, WHEAT SOYBEAN AND SUNFLOWER IN HERMETIC PLASTIC BAGS

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ABSTRACT

This research makes focus on the effect of grain moisture content (MC) and storage time on the quality of corn, wheat, soybean and sunflower stored in hermetic plastic bags of 200 tonnes of capacity.

Grain samples were periodically collected during the entire storage time, and then quality tests were performed. Additionally, moisture content stratification and temperature changes were monitored for different grain layers. The study also included measurement of CO_2 and O_2 concentration of the interstitial atmosphere.

The main results indicated that the grain temperature in the hermetically sealed plastic bags followed the pattern of the ambient temperature throughout the year.

The average moisture content did not significantly change during the entire experiment for both dry and wet silo-bags. In general, no MC stratification was observed but in wet sunflower, where the top layer increased MC from 16.4 to 20.8% after 150 days of storage.

When the grain was stored at the market moisture content, no significant decrease in the quality parameters could be observed during 150 days of storage. Contrastingly, when grain was stored above the market moisture content, 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. 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 a tool for monitoring grain storability.

Keywords: Modified atmosphere, Grain, Quality.

INTRODUCTION

In Argentina, 95 million tonnes of wheat, corn, soybeans and sunflower were harvested in 2006/07 (SAGPyA, 2007). At the same time, the total permanent storage capacity of the country was estimated between 65 and 70 million tonnes, resulting in a shortage in storage capacity of about 25 to 30 million tonnes (PRECOP, 2007). Due to this insufficient storage capacity, an important proportion of the Argentine grain production had to be delivered directly from the field to the regional grain elevators and from there to the terminal ports. Other consequences are an insufficient truck fleet to transport the harvested crop from the field to the elevators, and terminal ports working at 100% of their capacity. On top of that, trucks are used as temporary storage at the terminal ports in long lines. As a result, grain producers have to pay higher prices for transportation and services at the elevator (drying, cleaning, etc) during the harvest time than during the off season. This inefficiency of the grain post-harvest system influenced the harvest operations and farm logistic, which increased production cost unreasonably.

To overcome these unfavorable circumstances, grain producers started to increase their on-farm storage capacity. By doing so, grain producers were able to store their grain on-farm and sell it after the harvest season, when not only the grain prices are usually higher, but also the service costs are lower. However, to build a new storage facility or update/enlarge an existing one is generally not affordable for most Argentine farmers. The main constraints are the high initial investment, high interest rate and short loan maturation period. Under these circumstances, a new storage technique has gained popularity among farmers. This technique has been on the market for many years for storing wet grain for feed (grain silage) and then was adapted for storing dry grain. It consists of storing grain in hermetically sealed plastic bags ("silo-bags"). Each bag can hold approximately 200 tonnes of grain and with the available handling equipment is very easy to fill. Local companies also developed machineries to unload the plastic bag transferring the grain directly to the track or wagon. The new generation of high capacity combines found in the silo-bag system the ideal partner, since the loading capacity of the bagging machine is basically limited to the transportation capacity between the combine and the place where the bag is filled. Other advantage of the silo-bags is that they can be easily incorporated into grain identity preservation (IP) programs. Silo-bags can be easily set up in the field, right next to the crop, reducing risks of contamination of the specialty grain with other commodities. Many wheat growers have found in the silo-bag system the ideal tool to segregate different wheat varieties directly in the field.

In 2001, around 2 million tonnes of grain (corn, wheat, soybean and sunflower) were stored with this system. During the past few years, this storage technique has been further refined and the "silo-bag" system has gained rapid adoption among Argentine farmers, up to the point that in year 2007 about 22-25 million tonnes were stored in the silo-bags systems (more than 23 % of the total production).

These plastic bags are waterproof and have certain degree of gas-tightness (O_2 and CO_2). As a result, respiration of the biotic components of the grain mass (fungi, arthropods, and grain) increases CO_2 and reduces O_2 concentrations.

The effect of low oxygen concentration on insects is called anoxia. Oxygen level below 3% is required for effective control of insects (below 1% if rapid killing is required) (Banks and Annis, 1990 and Adler et al., 2000). The effect of high carbon dioxide concentration is called hypercarbia. The exposure time required to achieve complete control of insects is inversely proportional to CO_2 concentration. The minimum CO_2 concentration required to achieve total insect control seems to be 35%, with an exposure time longer than 14 days. However, different insect species have different tolerance to hypercarbia, as well as the insect stage (Navarro and Donahaye, 2005). Under self modified atmospheres treatments, the increase on the CO_2 concentration corresponds to a decrease in the O_2 concentration, so a combined effect is obtained and insect killing could be achieved more easily due to a synergistic effect (Calderon and Navarro, 1980). Additionally, the plastic material proved to be an efficient physical barrier that prevents insects from getting into the grain bag.

Low O2 concentration (below 1%) seems to be not sufficient to stop mold growth, although grain deterioration was delayed. Increasing CO2 concentration from 3 to 30% (even with O2 concentrations of 21%) resulted in a reduction of fungal counts. The combination of high CO2 and low O2 concentrations retarded mold growth. The latent period for growth of storage fungi in low O2 concentration (less than 1%) were longer than of the field fungi. However, the storage fungi were much tolerant to low a_w (low equilibrium relative humidity) than were the field fungi. When the CO_2 concentration increased to 15%, the lag phase of field and storage fungi increased for all a_w levels (Navarro and Donahaye, 2005). Wilson and Jay (1975) reported that mold appeared later in grain stored under modified atmosphere storage condition compared to control.

Aerobic fungi are predominant in bulk grain, and they find suitable conditions for proliferating and multiplying under normal atmosphere composition. However, low O_2 and high CO_2 concentration reduces (even suppresses) the viability of the fungi, expressed as rate of growth, degree of sporulation, respiratory rate and finally their ability to attack grain tissues (Navarro and Donahaye, 2005).

The ability of A. flavus to produce aflatoxin in groundnuts under optimal temperature and moisture conditions for mold growth was substantially reduced with the increase on CO_2 and decrease on O_2 concentrations. The primary cause of inhibition was the high CO_2 concentration, rather than the low O_2 concentration, and after the colonies were returned to normal atmosphere, mycotoxins can be produced (Landers et al., 1986).

The effect of high CO_2 concentration on seed viability was studied, and it was observed that seeds below their critical moisture content (MC) are not significantly affected at high CO_2 or low O_2 concentration (Banks, 1981). However, seed stored at high MC could result with reduction in the germination test due to the interfering effect of the CO_2 with the enzymatic activity of glutamine-decarboxylase (Münzing and Bolling, 1985). It was observed that the negative effect of CO_2 was more pronounced with temperatures above 47°C, but this effect was not noticeable with temperatures bellow 30°C (Banks and Annis, 1990). Seeds stored in the silo-bags usually have temperatures below 30°C, thus it should not be expected a noticeable reduction on seed viability due to high CO_2 concentration.

The National Institute of Agricultural Technologies (INTA) of Argentina has been conducting research on storage of grain and oilseed in hermetic plastic bags since year 2000 (Bartosik et al., 2002). The main goals of these experiments were to study the effect of MC, temperature and storage time on quality of corn, wheat, soybean and sunflower.

MATERIALS AND METHODS

The tests were carried out on farms in the south east of Buenos Aires province, Argentina. The dimensions of the bags were 67 m long (220 ft), 2.74 m diameter (9 ft), and 235 microns thick. The bags are made of a plastic material with three layers, black on the interior side and white on the exterior (Figure 1). This material is airtight and does not allow water and/or gasses to pass in or out. Each bag held roughly 200 tonnes of wheat, corn and soybean, and 120 tonnes of sunflower. The bags were filled with fresh grain right after the harvest, in the same plots were the crops were planted.

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

The grain stored in plastic bags was sampled at the beginning of the experiment and after 45, 80, and 150 days. Samples were taken with a simple truck probe. The plastic cover was punctured at three locations along the length of the bag. At each one of these locations grain was sampled at three different levels (surface= 0.10 m depth, middle= 0.75 m depth, and interior= 1.6 m depth. Total height of the bag= 1.7 m). Material from each one of the three sampling locations was segregated by level (surface, middle, and interior). Then, grain from superior level of each sampling location was blended all together, conforming a compounded sample for superior level. The same procedure was applied to samples from middle and interior levels. After probing the bags, the holes were sealed with special plastic tape to keep the system hermetically sealed. In order to track any change in the quality of the grain, several quality tests were performed on each of the sub samples (test weight, germination test, composition, oil acidity for soybean and sunflower, and baking quality for wheat). The MC of the grain at different levels was monitored, as well as the grain temperature. MC was determined by oven drying at 103 ºC for 72 h (ASAE, 1983). Temperature was monitored by dataloggers every 10 minutes during the experimental period. Carbon dioxide (CO_2) and oxygen (O_2) levels at different depths were also monitored after 5 and 100 days of storage time using a fast gas analyzer (ABISSPRINT, Abiss, Viry Chatillon, France). The effect of the modified atmosphere on insect activity was also investigated. Bags made of fine a plastic mesh containing grain (wheat) and 50 rice weevils (Sitopillus orizae (L.)) were placed in a plastic pipe with holes to facilitate gas flow between the interstitial grain air in the grain bulk and the inside of the pipe. These pipes were inserted into the grain mass extending through the three depths (surface, medium and interior). For each depth and sampling date three replicates were analyzed.

The wheat experiment started on January 2nd, 2001 (variety ProINTA-Isla Verde). One bag was filled with dry wheat (12.5%) and the other with wet wheat (16.4%). After the bags were filled, the ends were sealed and the grain was not disturbed until the end of the test on June 4th (150 days).

The sunflower experiment started on March 8th, 2001 (hybrid Van der Haven 480). One bag was filled with dry sunflower (8.4%) and the other with wet sunflower (16.4%). The grain was hold in the bags during 160 days (August 15th).

The corn experiment started on July 6th, 2001 (hybrid Axel, Sursem). One bag was filled with dry corn (14.8%) and the other with wet corn (19.5%). The grain was hold in the bags during 153 days (December 5th).

The soybean experiment started on June 5th, 2001 (variety Nidera 4100). One bag was filled with dry soybean (12.5%) and the other with wet soybean (15.6%). The grain was hold in the bags during 160 days (November 12th).

RESULTS AND DISCUSSION

Temperature

The main results indicated that the grain temperature in the hermetically sealed plastic bags followed the pattern of the average ambient temperature. For instance, when wheat is harvested and bagged in the early summer (January), the grain temperature starts with a maximum and then decreases, following the drop of the ambient air temperature during the fall, and reaching the minimum during the winter (June) (Figure 2). On the other hand, when corn is harvested and bagged in the late fall or winter, the grain temperature starts with a minimum and then increases following the rise of the ambient air temperature during the spring, and reaching the maximum during the summer (Figure 3).

The silo-bags with wheat and sunflower were set up during the summer time, with grain temperatures close to 40°C and 30°C respectively. The silo-bag was able to dissipate the accumulated heat in the grain to the ambient air and the soil in a couple of months. This could be explained with the relation volume/surface, which is substantially lower for silo-bags (0.7 for a 200 tonnes silo-bag) than for a regular bin of similar storage capacity (1.27 for a 7 m diameter and 9 m height bin of 200 tonnes of capacity). Wheat and sunflower harvested in summer time reached the safe storage temperature for preventing insect development (below 17°C) by early May (Figure 2), while soybean and corn, harvested during the fall and winter, were able to maintain the temperature below 17°C until early November (Figure 3).

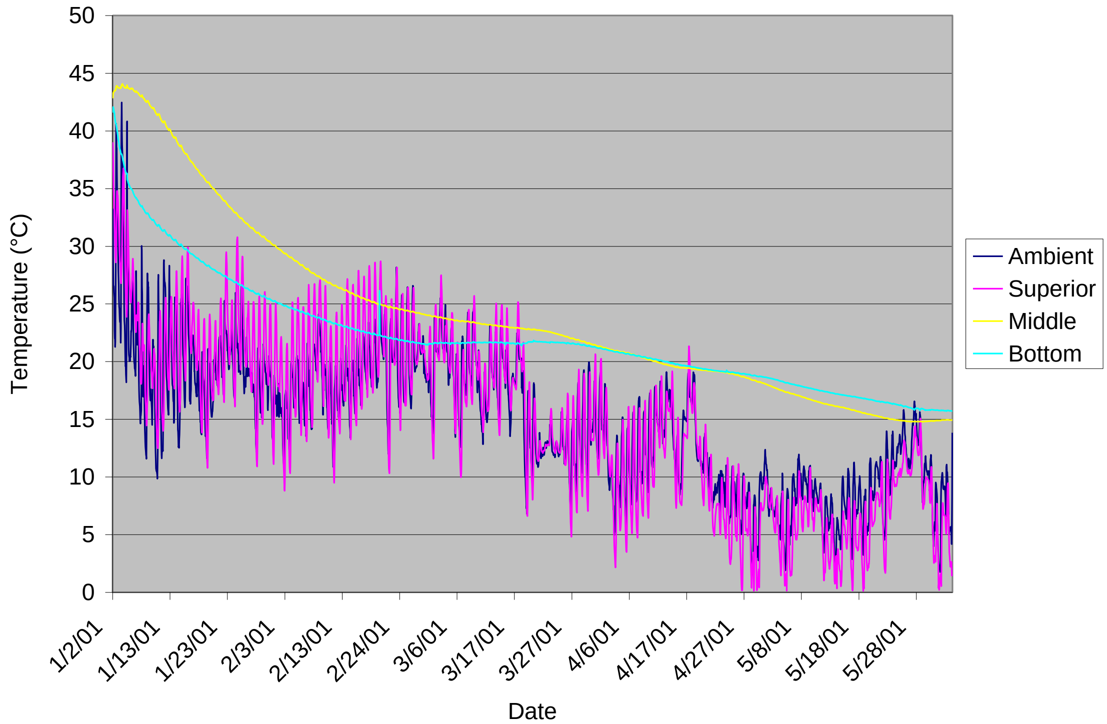

Figure 2. Temperature pattern at different grain depths (surface, middle and bottom) during storage of wheat in a silo-bag, from January to June.

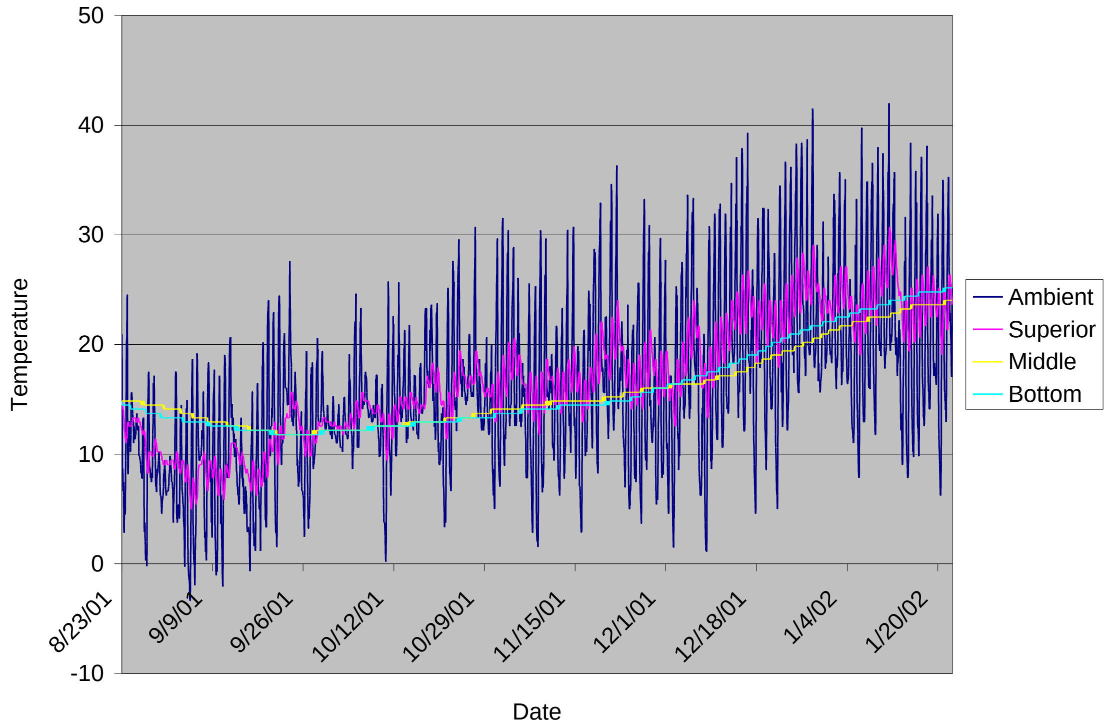

Figure 3. Temperature pattern at different grain depths (surface, middle and bottom) during storage of corn in a silo-bag from August to January.

At the surface of the grain, the temperature showed the distinctive pattern of the ambient air temperature, reaching its maximum at noon and minimum during the early morning (Figures 2 and 3). The daily temperature oscillation decreased with the grain depth, being not noticeable after 0.7 m depth. The larger temperature change at the surface level could cause moisture change due to water condensation (during the night) and relative humidity change at the interstitial air close to the grain surface.

<u>Moisture Content</u>

Tables 1 and 2 show the MC of the grain at three different levels (top: 0.1 m from the surface, middle: 0.75 m from surface, and bottom: 1.5 m from surface) at the beginning of the experiment and after 150 days of storage. The average MC did not substantially change during the entire experiment for both dry and wet silo-bags, and most of the differences could be explained by the precision of the moisture meter and the experimental error during the sampling operation. It was not observed, in general, a substantial moisture stratification during storage, with the exception of the wet sunflower silo-bag. For this grain, the MC at the top layer increased from 16.4% to 20.8% during the experiment. The substantial MC increase at the top grain layer could be caused by repeated cycles of water condensation at the top grain layer. The equilibrium relative humidity of 16.4% MC sunflower is above 90% at 15°C. With the temperature decrease during the night, the relative humidity could easily increase up to 100% and condensate on the grain surface and plastic cover, increasing, in the long time, the grain MC at the top layer. This condition of high MC (and high RH%) at the top grain layer created suitable conditions for developing of yeast and other anaerobic microorganisms, which are not normally observed when dry grain is stored.

Table 1. Moisture content of the dry grain silo-bags at three different levels (top: 0.1 m from the surface, middle: 0.75 m from surface, and bottom: 1.5 m from surface) at the beginning of the experiment and after 150 days of storage.

Position	Wheat		Corn		Soybean		Sunflower	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Top	12.5	13.5	14.8	14.2	12.5	12.9	8.4	8.3
Middle	12.5	13.4	14.8	14.5	12.5	12.6	8.4	8.6
Bottom	12.5	12.9	14.8	14.5	12.5	12.6	8.4	9.6

Table 2. Moisture content of the wet grain silo-bags at three different levels (top: 0.1 m from the surface, middle: 0.75 m from surface, and bottom: 1.5 m from surface) at the beginning of the experiment and after 150 days of storage.

Position	Wheat		Corn		Soybean		Sunflower	
	Initial	Final	Inicial	Final	Initial	Final	Initial	Final
Top	16.4	15.7	19.5	18.8	15.6	15.7	16.4	20.8
Middle	16.4	16	19.5	18.8	15.6	15.6	16.4	17.6
Bottom	16.4	16.1	19.5	18.7	15.6	15.5	16.4	15.5

Grain Quality

In general for all grains, when the grain was stored at the market MC (or below market MC), no significant decrease was observed during 150 days of storage for most of the quality parameters considered. However, some quality parameters such as germination test, resulted slightly affected. Contrastingly, when grain was stored above the market MC corresponding to the grain, a certain degree of decrease in some of the quality parameter was observed (from almost noticeable to severe) after 150 days of storage.

Table 3 shows the effect of storage time on dry and wet wheat quality parameters. When wheat was bagged at 12.5% MC no substantial reduction in test weight was observed, while the germination test decreased from 93 to 87%. This 6 percentage points of reduction did not prevent the use of the stored wheat as seed for the following planting season (in Argentina farmers are allowed to store their own seed for the next planting season, and this is a common practice). The baking quality parameters for dry wheat did not substantially change after 150 days of storage, making suitable this storage technology for storing wheat for flour milling purpose.

When 16.4% MC wheat was bagged in January, the ambient temperature was in the low 40's, so the average grain temperature was close to 42°C. The combination of high MC and high temperature resulted in a substantial decrease on most of the quality parameters evaluated. The test weight decreased from 78.7 to 77.3 kh/hl, although this decrease did not change the commercial grade of the wheat. The germination test decreased from 95 to 40%, which prevented the use of the grain as seed for the next planting season. Additionally, all the baking quality parameters resulted negatively affected, making this wet wheat not suitable for flour milling purposes.

Wheat is harvested during the early summer (December-January), with ambient air temperatures above 30°C. Thus, wheat is usually bagged at 30°C or more, and stored through all summer and early fall with relatively high temperatures, before the ambient temperature starts to cool down in the late fall and winter. Therefore, the combination of high storage temperature and grain MC results in high biological activity, with the subsequent negative effect on wheat quality parameters during storage. On the other hand, storage of wheat during 5 months with low MC (below 14%) results a safe storage condition.

Table 3. Wheat quality parameters at the beginning of the experiment and after 150 days of storage in hermetic plastic bag.

Sampling time	Test weight (kg/hl)	Germination test (%)	Baking quality parameters					
			Gluten (%)	W	P/L	Abs.[a]	LV (cm^3)[b]	SV[c]
Dry Wheat (12.5%)								
Initial	82.4	93.0	30.2	282	0.9	61	620	4.3
Final (150 days)	82.0	87.0	27.8	313	1.1	62	655	4.5
Wet Wheat (16.4%)								
Initial	78.7	95.0	29.8	288	1.0	61	675	4.7
Final (150 days)	77.3	40.0	22.6	283	2.6	61	578	4.0

References: [a] = Water absorption, [b] = Loaf volume, [c] = Specific volume

Table 4 shows the effect of storage time on dry and wet corn quality parameters. The grain bagged at 14.8% MC resulted with a slightly higher test weight after 150 days of storage, while the percentage of damaged kernels increased by 1.3 percentage points. Since the initial dry corn samples were above the damaged kernel tolerance for the argentine standard (3%), the change in this quality factor did not affect the commercial grade of corn.

The wet corn samples (19.5% MC) resulted with a reduction in the test weight of 2 kg/hl, and a substantial increase of the damaged corn faction of 4.4 percentage points.

Corn is harvested during the fall, with decreasing ambient air temperatures. Thus, corn is usually bagged at 20°C or less, and stored during the winter with ambient air temperatures below 15°C average. As a result, wet corn (18% MC) is usually stored without substantial decrease in quality parameters until spring (September), because the grain remains at 15°C or below. Thereafter, with the temperature increase during spring increases the biological activity inside the silo-bag, resulting in substantial deterioration of the corn quality parameters during late spring. Storage of dry corn (below 15%) during 5 months results in a safe practice, while storage of wet corn beyond winter time (more than 3 months), usually results in negative effects on grain quality parameters.

Table 4. Corn quality parameters at the beginning of the experiment and after 150 days of storage in hermetic plastic bag.

Sampling time (days)	Test weight (kg/hl)	Damaged kernels (%)
Dry Corn (14.8%)		
Initial	73.0	3.2
Final (150 days)	74.0	4.5

Wet corn (19.5%)		
Initial	72.0	5.8
Final (150 days)	70.0	10.2

Table 5 shows the effect of storage time on dry and wet soybean quality parameters. The soybean bagged at 12.5% MC did not substantially modify the test weight and oil percentage of the samples. On the other hand, the oil acidity index and the germination test were, somehow, affected. The decrease on germination test (from 74 to 62%) indicated that precautions should be taken when the soybean is to be used as seed for the next planting season. In Argentina, the base MC for soybean commercialization is 13.5%. According to the Modified Chung-Pfost EMC equation and the parameters available in the ASABE D245.5 standard, the equilibrium relative humidity of 67% (considered the safe storage MC) corresponds to a MC substantially below 13.5% (Figure 4). Thus, if soybean will be stored in plastic bags to be used as seed in the next planting season, the bagging MC should be below 12.5% MC.

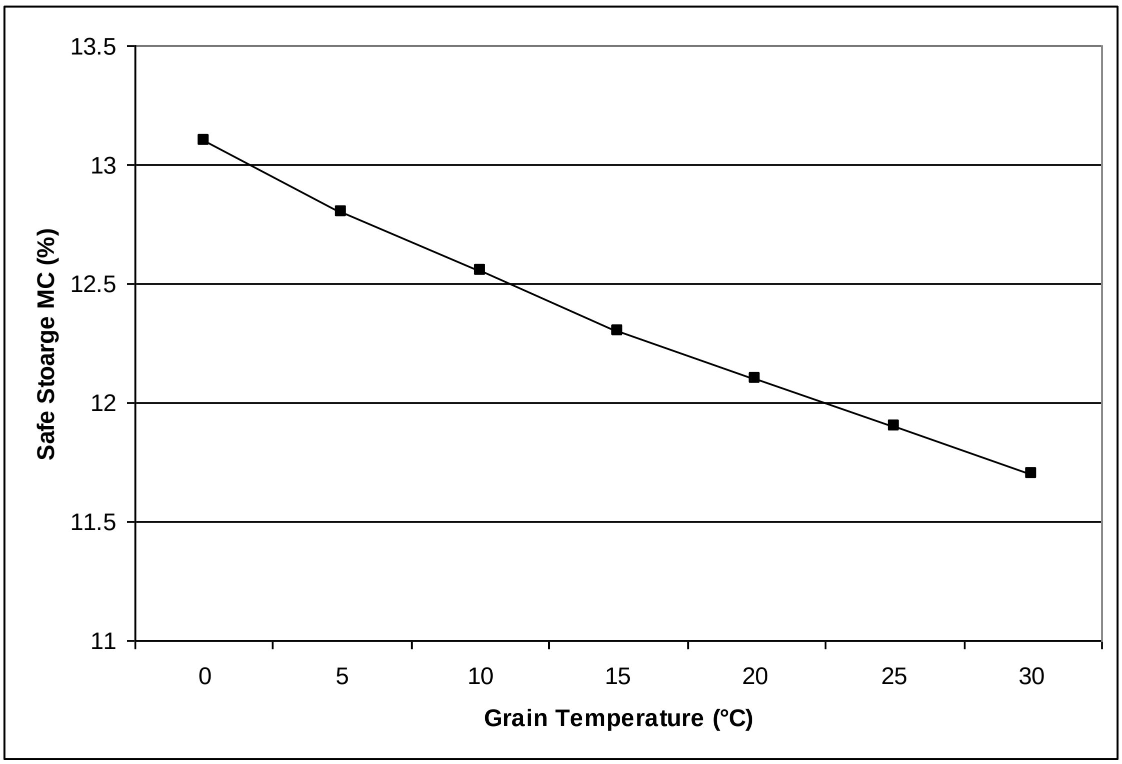

Figure 4. Safe storage MC (equilibrium relative humidity of 67%) for soybean at different storage temperatures [Modified Chung-Pfost equation and ASABE D245.5 parameter standard].

The wet soybean samples (15.6% MC) resulted with a reduction in the test weight of 2 kg/hl, and a substantial increase of the damaged corn faction of 4.4 percentage points.

Soybean is harvested like corn, during the fall, with decreasing ambient air temperatures. Thus, soybean is usually bagged at 20°C or less, and stored during the winter with ambient air temperatures below 15°C average. As a result, wet soybean (above 13.5% MC) is usually stored without substantial decrease in quality parameters until spring (September), because the grain remains at 15°C or below. Thereafter, with the temperature increase during spring, increases the biological activity inside the silo-bag, resulting in substantial deterioration of the soybean quality parameters during late spring. Storage of dry soybean (below 13.5%) during 5 months results in a safe practice (excepting for maintaining the germination test values, which requires storing soybeans below 12.5%), while storage of wet soybean beyond winter time (more than 3 months), usually results in negative effects on grain quality parameters.

Table 5. Soybean quality parameters at the beginning of the experiment and after 150 days of storage in hermetic plastic bag.

Sampling time (days)	Germination test (%)	Test weight (kg/hl)	Oil composition (%)	Oil acidity index (%)
Dry Soybean (12.5%)				
Initial	74.0	71.0	20.8	1.6
Final (150 days)	62.0	71.0	20.5	1.9
Wet Soybean (15.6%)				
Initial	74.0	68.5	21.5	1.7
Final (150 days)	55.0	68.9	21.0	2.3

Table 6 shows the effect of storage time on dry and wet sunflower quality parameters. When sunflower was bagged at 8.4% MC no reduction in oil composition was observed, while the oil acidity index slightly increased from 0.9 to 1.4. This increase in the oil acidity index did not affect the standard grade of sunflower, since the oil acidity index limit for the argentine standard is of 1.5% until August 31, and 2% thereafter. Thus, storage of dry sunflower (below 11% MC) is a safe practice, since the industrial quality parameters were not affected after 150 storage days.

Storing of wet sunflower (16.4%) resulted in a reduction of oil composition of 1.3 percentage points (from 47.0 to 45.7%) after 150 storage days, and a more substantial increase in the oil acidity index (0.9 to 3.9%).

Sunflower is harvested during the late summer (February), with ambient air temperatures above 20°C. Thus, sunflower is usually bagged at 20-25°C or more, and stored through the late summer and early fall with relatively high temperatures, before the ambient temperature starts to cool down in the late fall and winter. Therefore, the combination of relatively high storage temperature and grain MC results in high biological activity, with the subsequent negative effect on industrial sunflower quality parameters during storage. On the other hand, storage of sunflower during 5 months with low MC (below 11%) results a safe storage condition.

Table 6. Sunflower quality parameters at the beginning of the experiment and after 150 days of storage in hermetic plastic bag.

Sampling time (days)	Oil composition (%)	Oil acidity index (%)
Dry Sunflower (8.4%)		
Initial	49.0	0.9
Final (150 days)	49.0	1.4
Wet Sunflower (16.4%)		
Initial	47.0	0.9

Final (150 days)	45.7	3.9

Atmosphere Composition

Grain and associated microorganism respiration produces an increase in the CO_2 concentration and reduction in the O_2 concentration. Tables 7 to 10 show the change in the interstitial atmospheric composition during storage time for dry and wet wheat, corn, soybean and sunflower. The increase in the CO_2 and reduction in the O_2 concentrations were higher at the end of the storage time. It was also observed that, for any grain, the increase in the CO_2 and reduction in the O_2 concentrations were higher for the wet than for the dry grain silo-bags, with the exception of corn, where both silo-bags presented similar values of CO_2 and O_2 (Table 8). The higher CO_2 concentration observed in the wet grain plastic bag was an expected result, since the higher grain MC is able to support higher biological activity (mold growth). Thus, the higher respiration rate resulted in a more substantial modification of the interstitial atmosphere. In the case of the corn experiment, where the dry and wet corn plastic bag resulted with high and similar CO_2 concentration (about 18%), it was speculated that the dry corn plastic bag had a portion of the grain in decomposition (most likely due to breakages in the plastic film at the bottom caused by the stems of the former crop, which often allow water coming inside the bag). The CO_2 and O_2 concentrations in the wet sunflower plastic bags reached 70.3 and 4.9%, respectively (Table 10). This significant change in gas composition was most likely caused by the high biological activity that 16.4% MC sunflower can support (the safe storage MC for sunflower is below 11%). Thus, 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 a tool for monitoring grain storability.

Table 7. Change during storage time of carbon dioxide (CO_2) and oxygen (O_2) concentrations in the interstitial atmosphere of wheat stored in the silo-bag.

Grain Condition	5 days		100 days	
	CO_2	O_2	CO_2	O_2
Dry wheat (12.5%)	4.4	14.7	13.0	10.4
Wet wheat (16.4%)	18.9	5.5	22.8	5.6

Table 8. Change during storage time of carbon dioxide (CO_2) and oxygen (O_2) concentrations in the interstitial atmosphere of corn stored in the silo-bag.

Grain Condition	20 days		35 days		52 days		79 days		84 days	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
Dry corn (14.8%)	-	-	9.7	10.4	18.2	2.1	18.2	2.1	-	-
Wet corn (19.5%)	6.2	12.8	-	-	-	-	-	-	18.5	2.6

Table 9. Change during storage time of carbon dioxide (CO_2) and oxygen (O_2) concentrations in the interstitial atmosphere of soybean stored in the silo-bag.

Grain Condition	30 days		46 days		93 days		160 days	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
Dry soybean (12.5%)	3.5	15.5	3.8	14.2	4.5	11.3	7.5	10.0
Wet soybean (15.6%)	5.7	7.7	6.8	5.2	9.2	4.8	16.2	3.0

Table 10. Change during storage time of carbon dioxide (CO_2) and oxygen (O_2) concentrations in the interstitial atmosphere of sunflower stored in the silo-bag.

Grain Condition	34 days		125 days	
	CO_2	O_2	CO_2	O_2
Dry sunflower (8.4%)	16.5	5.1	18.9	4.5
Wet sunflower (16.4%)	70.3	4.9	69.1	4.7

CONCLUSION

The temperature of the grain stored in the hermetic plastic bags followed the typical pattern of the average ambient temperature throughout the season. No temperature rise due to biological activity was observed (even in wet grain storage). Grain stored in the plastic bag remained below 17°C (temperature limit for insect development) during the cold part of the year.

The average MC of the grain mass did not change during storage. Moisture stratification was observed in wet sunflower, which increased MC at the surface from 16.4 to 20.8% during more than 150 days of storage.

In general, when grain was stored at the market MC or below (14% for wheat, 14.5% for corn, 13.5% for soybean and 11% for sunflower), no significant decrease in the quality parameters was observed after 150 days of storage. When grain was stored wet (above market MC), a decrease on one or more quality parameters was observed, and that decrease was more severe for higher MC grain. The combination of high grain temperature (warm part of the year) and high MC resulted in greater quality loss.

CO_2 concentration increased during storage time for all grains. Wet grain had a higher degree of modification of the interstitial atmosphere, due to the higher biological activity. 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 a tool for monitoring grain storability.

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REFERENCES

1. Adler, C., H.G. Corinth and C. Reichmuth. 2000. Modified atmospheres, pp. 106-146, in Bh. Subramanyam and D.W. Hagstrum (Eds.), Alternative to Pesticides in Stored-product IPM. Kluwer Academic Publisher, Boston, USA.
2. ASAE Standards. 2001. ASAE D241.5. Moisture relationships of plant-based agricultural products. St. Joseph, Michigan, USA.
3. Banks, H.J. 1981. Effects of controlled atmosphere storage on grain quality: a review. Food Technol. Aust. 33:335-340.
4. Banks, H.J. and P.C. Annis. 1990. Comparative advantages of high CO2 and low O2 types of controlled atmospheres for grain storage, pp. 93-122, in M. Calderon and R. Borkai-Golan (Eds.), Food Preservation by Modified Atmospheres, CRC Press, Boca Raton, Florida, USA.
5. Bartosik, R. E., J.C. Rodriguez, H.E. Malinarich, and D. E. Maier. 2002. “Silobag”: evaluation of a new technique for temporary storage of wheat in the field. Proceedings of the 8th International Working Conference on Stored Product Protection, pages 1018-1023, York, England.
6. Calderon, M. and S. Navarro. 1980. Synergistic effect of CO2 and O2 mixture on stored grain insects, pp. 79-84, in J. Shejbal (Ed.), Controlled Atmosphere Storage of Grains. Elsevier, Amsterdam.
7. Landers, K.E., N.D. Davis and U.L. Diener. 1986. Influence of atmospheric gases on aflatoxin production by Aspergillus flavus in peanuts. Phytopathology 57: 1967.
8. Münzing, K. and H. Bolling. 1985. Qualitatsveranderungen von Weizen durch CA-Lagerung. Verjffentlichungsnr. 5309 der Bundesforschungssanst. Für Getreide- und Kartoffelverarbeitung, Detmold, 22 S.
9. Navarro S. and J. Donahaye. 2005. Innovative environmentally friendly technologies to maintain quality of durable agricultural produce, pp. 203-260, in Shimshon Ben Yeoshua (Ed.), Environmentally Friendly Technologies for Agricultural Produce Quality. CRC Press, Boca Ratón, Florida, USA.
10. PRECOP, 2007. In Spanish “Post-harvest efficiency: generation, development and extension of suitable technologies to increase the efficiency of conditioning, drying and storing of cereal grains, oilseeds and industrial crops”. National project of the National Institute of Agricultural Technologies. INTA PE AEAI5742.
11. SAGPyA, 2007. In Spanish “Monthly agricultural statistics – Official estimations at October 17 of 2007”. Report of the Secretary of Agriculture. Available at: www.sagpya.gov.ar. Accessed on October 2007.
12. Wilson, D. M. and E. Jay. 1975. Influence of modified atmosphere storage on aflatoxin production in high moisture corn. *Appl. Microbiol*. 19: 271.