Study of Grain Storage in Plastic Bags Aimed at Small-scale Farmers.

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ABSTRACT

Grain storage performed by small farmers results in considerable losses, often reaching values above 30% in grain quantity and quality. One of the main problems small producers face is insect infestation that causes severe grain damage, at times leading to complete losses. Efficient and safe organic methods to control insects attacking stored grains are scare. Grain storage in plastic bags has been studied in large-scale productions, in which an atmosphere of high CO_2 concentration and O_2 reduction directly related to grain moisture develops inside the bag. In this atmosphere, greater grain moisture results in higher CO_2 concentration. It should be noted that this system has not been tested for small-scale grain production, which is generally stored in small bags of about 60 kg or in 200-L drums. The aim of this work is to study storage of dry corn (*Zea mays*) grains (14% of moisture) in 40 kg hermetic plastic bags, a system that can be adapted to small producers. Bags were filled with dry corn grains; different proportions of moist corn grains were placed in screened plastic tubes of 100 mm in diameter, to generate a greater CO_2 concentration inside the bag. Thus, a natural system of self-modified atmosphere is created, which is efficient in insect control and grain storage and poses no risk of damage or contamination. The results of the experiment showed that this is an efficient method for storing dry corn grains, which attains sound organic insect control; plastic bags therefore become a new and low-cost storage method for small producers.

Keywords: Plastic bags, small farmers, insect control, corn, Argentina.

1. INTRODUCTION

According to a report of the United Nations Food and Agriculture Organization (FAO), most foodgrains harvested in temperate areas are lost due to inappropriate management systems, storage, and processing techniques. Global losses have been estimated between 10% and 30%; in some regions of the world production losses can be as high as 50%. These percentages include not only physical damage caused by mechanical friction of grains and unavoidable breakage during some processes, but also losses in quality and in factors affecting nutritional level and conservation of grains. Taking into account storage conditions is crucial because they are key

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factors in grain spoilage. High temperatures and humidity contribute to fungus growth and provide suitable conditions for insect development, the most common and important causes of postharvest losses.

Insects are a serious threat during postharvest. Of the ten million insect species believed to exist, only two million have been recognized; of these, 80 species are harmful to grains, since the effects of insects feeding on stored grains involve weight loss, nutrient degradation, deterioration of seed germination and reduction in commercial value. For example, adults of *Sitophilus oryzae* L. and *S. granarius* L. have been reported to consume 26% and 56% of the grain where they develop, respectively (Dell`Orto Trivelli and Arias Velazquez, 1985). The same authors also found that, under laboratory conditions, a larva of *S. oryzae* L. consumes 1.55% of the wheat grain weight at 9 days, with a 39.72% loss at 72 days.

Besides damage produced by feeding, insects generate secondary damage, such as heating and moisture migration, distribution of fungi and other microorganisms, because insect attack increases moisture and enhances conditions for the naturally developing fungus spores. Insects also act as a means of distribution of aflatoxins and other mycotoxins; they are also vectors of human diseases, such as tapeworm diseases and intestinal infections like ascariasis, myasis and chantariasis. Grain itch caused by weevils and mites can also occur. Grain contamination (through insect faeces or insecticide residues) and costs of treatments with chemical products are additional pest-related problems (Yanucci, 1998).

The life cycle of these pests averages between 4-8 months (depending on the species), with each female laying 300-400 eggs in the germ or in the starchy zone. The cycle from egg to adult is of approximately 35 days, depending on environmental conditions; optimal temperatures for development range between 22 and 34 ºC, which makes them cosmopolitan and of rapid dissemination. Therefore, control measures are imperative and very often cannot be implemented by small farmers because, among other factors, traditional storage systems used have evolved at a very slow pace. In many places, design and materials used for grain storage vary with local resources and traditions, and in most cases this is not consistent with an adequate management to preserve grain quality, which in turn does not allow the correct implementation of measures to control pests.

A requirement for the proper functioning of storage structures is a design that facilitates control and especially that keeps the product isolated; also, the structure should not have any fissures or tears or any type of structure that provides habitat for the different pests that may affect the product stored.

Accordingly, plastic bags for large-scale grain storage meet these requirements because they act as a physical barrier to insect entry and because inside them conditions are unsuitable for insect and fungus development due to self-modification of the intergranular atmosphere (Casini, 2002); in addition, bags are only used once and therefore do not become reservoirs for pest infestation.

These bags are manufactured with low density polyethylene, of approximately 235 μm in thickness, using extrusion technology. The outer layer is white and has additives (UV-radiation filters and titanium dioxide) to reflect solar radiation. The middle layer is neutral and the inner layer has one additive (carbon black) that protects the bag contents from UV radiation and keeps out the sunlight. The bag composition makes it waterproof and gas-tight. This characteristic generates changes in gas composition within the grain mass over a period that depends on factors such as humidity and temperature, both conditioning respiration of biotic grain mass components (grains, fungi, bacteria, yeasts, insects).

Grain moisture content (m.c.) invariably generates a greater metabolic activity, heat, greater respiration and higher CO_2 production. Increases in temperature also generate increases in respiration up to a point at which O_2 concentration is limited and respiratory rhythm is reduced. These processes occurring inside the bags generate changes in concentration of gases that ameliorate grain damage because of O_2 absence, thus improving grain conservation due to reduction of oxidation processes (Hall, 1980). In turn, variation in concentration of gases in the intergranular atmosphere generates organic control of fungi and insects, because these organisms are the first ones to suffer the effects of excess of CO_2 and lack of O_2; thus, first eggs are controlled, then larvae, adults, and finally pupae (Navarro and Donahaye, 1993). Because the system is hermetic, no insecticides are used to control insects and the risk of mycotoxin development is very low provided that the bag remains intact.

As postharvest losses cannot be reduced to zero, they must be compensated for by production surplus. For this compensation to be effective, production increase rate should be gradually higher than loss rate. Thus, to compensate for a 10% loss, additional production should be of 11%; for a 30% loss, additional production should be 43%, and for 50% loss, 100% extra production is necessary (Bourne, 1977). This simple calculation stresses the importance of developing and implementing measures to reduce losses during storage period to the minimum. Postharvest losses are more evident in small-scale farms because small farmers cannot exert appropriate control.

This work aims at studying corn storage with grain m.c. close to 14%, in hermetic plastic bags of 40 kg of capacity, a system that can be adapted by small farmers. The system consists in incorporating screened tubes containing moist corn (in different proportions) and green chopped corn fodder to generate a greater CO_2 concentration inside the bag. Thus, a natural system of self-modified atmosphere is created, which is efficient and viable for insect control, of low cost to small-scale farmers, and allows grain preservation without damage or contamination.

2. MATERIALS AND METHODS

The assay was conducted at the Estación Experimental Agropecuaria INTA Manfredi, province of Córdoba, 31° 49' 12" S, 63° 46' 00" W, 292 m a.s.l. Field corn (Pioneer 32FO7) was used, which at the moment of storage had an average grain m.c. of 14.1%, and a temperature of about 26 ºC. The assay was performed in a closed room to maintain a stable environment between 18 and 25 ºC (temperature values favourable for insect development).

The assay started in February 2009 and finished 70 days later, in April 2009. Mean final temperature was 23 ºC, a value that is within the optimal limits for insect development. Optimal temperature value depends on the species, insect development stage, and grain moisture content. The bags used for the present assay were of the same type as conventional plastic bags (low-density polyethylene of approximately 235 μm in thickness).

To increase CO_2 concentration inside the bags, screened PVC tubes were used. The tubes were 110 mm in diameter and 950 mm in length were used, which makes up a theoretical volume of 9028 cm^3. Twelve lines of perforations of approximately 5 mm in diameter were made to the tubes at 35 mm intervals, with the aim of ensuring diffusion of gases to the corn grains stored with $14.1\%_{bh.}$ moisture content. Inside the tubes, the following CO_2-generating materials were added: moist (20%) corn grains and green chopped corn fodder.

To analyze the effect of self-modification of the intergranular atmosphere on insects that usually cause stored grain losses, individuals of the species *Sitophilus zeamais Motschulsky* (Maize weevil), Order Coleoptera, Family Curculionidae, were employed. This insect species has a great flight capacity and infests cereals from the field. It attacks all cereals and is extraordinarily harmful. This species is considered a primary pest because adults are able to bore the grains.

Fifteen Maize weevil individuals and 0.075 kg of corn were placed inside small bags made of voile, a sheer fabric that allowed the passage of air of the intergranular atmosphere but kept insects inside the bag.

The plastic bags were placed in a vertical position; the tube containing moist grain was placed in the central part of the bag, so that gas diffusion in the stored material was the most homogenous possible; in addition, in each plastic bag that made up the different repetitions of the treatments a single voile bag with the 15 Maize weevil individuals was placed. Each plastic bag was filled with 40 kg of dry corn (14% m.c.) and then heat-sealed.

Levels of O_2 and CO_2 were measured with a gas analyzer, which determines the percentage of gases through sampling extraction by suction at atmospheric pressure. The device has a standard scale of 100%, an accuracy of +2% (relative value) for O_2 and of +2% for CO_2 at full scale, with a resolution of 0.01% for O_2 and of 0.1% for CO_2, Samples for gas concentration of intergranular atmosphere are taken by perforating the plastic bag with a hypodermic needle of 254 mm in length. Two samples per bag were taken, one from the bottom sector and the other from the top sector of each bag, both at midday during 70 days.

The following treatments were performed (three bags per treatment):

Treatment I ($T_{20\%}$): This treatment had a 20% proportion of moist weight corn to dry corn weight.

Treatment II ($T_{30\%}$): Proportion of moist corn weight to dry corn weight was 30%.

Treatment III ($T_{10\%}$): Proportion of moist corn weight to dry corn weight was 10%.

Treatment IV ($T_{5\%}$): Proportion of moist corn weight to dry corn weight was 5%.

Treatment V (T_f): Proportion of moist fodder weight with respect to dry corn was 6.25%.

Treatment VI (T_T): It consisted of dry corn only, to which only one voile bag with 0.075 kg of corn with the insects was added. This treatment was used as control to evaluate if modification of the atmosphere produced by dry grain affected the insect population.

3. RESULTS AND DISCUSSION

After 70 days of corn storage, bags were opened and live insects inside the small voile bags were counted. No live insects were found in any treatment, except for the control treatment, where 12 insects (average number of the three repetitions) were found, i.e., 80% of the initial number of individuals.

In all treatments mean grain moisture content was 14.1% and mean grain temperature was 23 ºC at the end of the assay. Based on these data, relative humidity of intergranular air was empirically estimated in approximately 65%, which is an optimal situation for insect development, suggesting that modification of the intergranular atmosphere was the factor responsible for insect control. For all the treatments, except the control treatment (T_T), O_2 and CO_2 concentrations varied abruptly (fig. 1 and 2). Concentration of O_2 fell from values close to 14% on day 1 of grain storage to mean values of about 1.37% (with a maximum of 3.1% and a minimum of 0.02%) from day 5 until the end of the assay. CO_2 concentration in treatments I to V increased from a mean of 6% on day 1 of grain storage to a mean of 20.37% from day 5 until the end of the assay, on day 70 of storage.

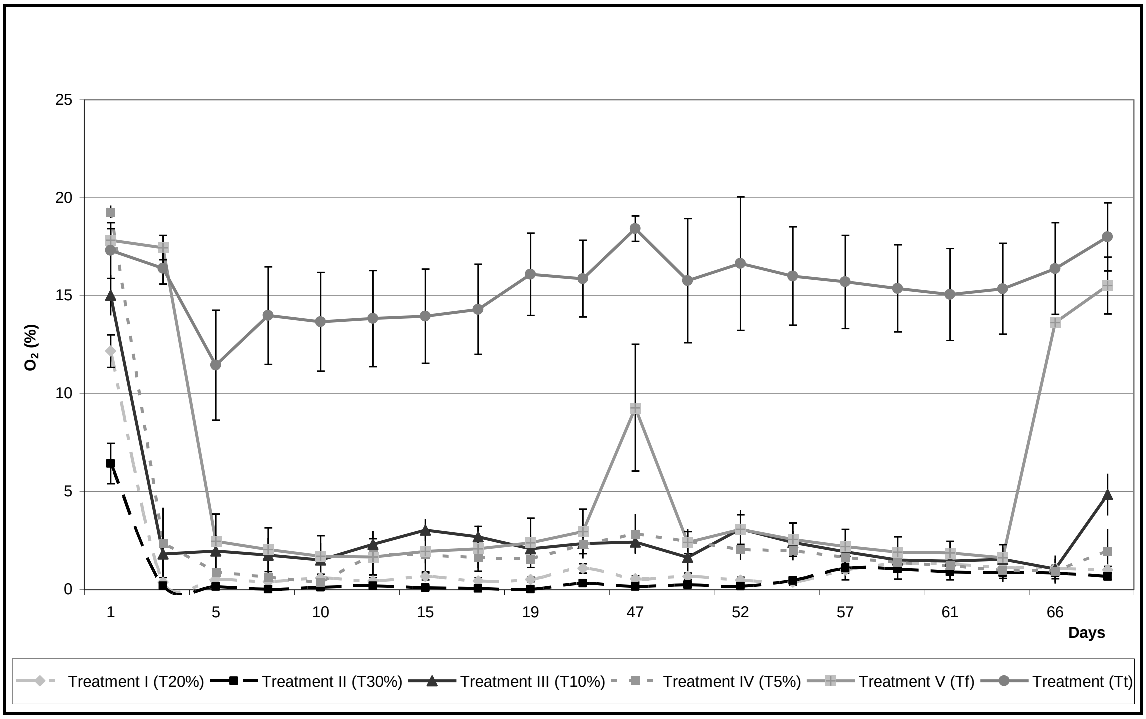

Figure 1. Oxygen concentration in the intergranular atmosphere throughout the assay.

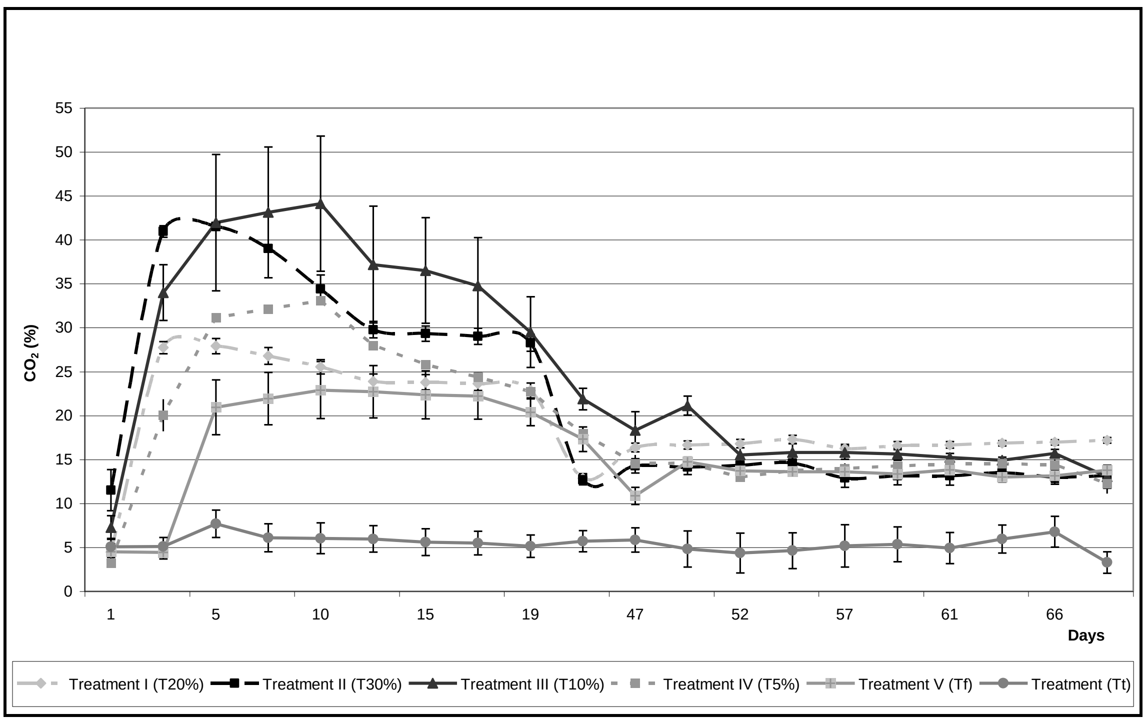

Figure 2. Carbon concentration in the intergranular atmosphere throughout the assay.

For the control treatment (T_T) mean O_2 concentration over the period evaluated was 15.38%, with a maximum of 18.42% and a minimum of 11.45%, whereas mean CO_2 concentration was 5.5%, with a maximum of 7.7 % and a minimum of 3.28%.

The levels of O_2 and CO_2 recorded in the different treatments, which killed the insects inside the voile bags, are in agreement with values reported by other authors (Casini and Santa Juliana, 2007). Indeed, these authors observed a total insect control in plastic bags of 9 ft in diameter at CO_2 and O_2 concentrations of 23.4% and 0.25%, respectively, whereas at CO_2 and O_2 concentrations of 10.5% and 5.85%, respectively, they detected live insects 90 days after placing the insects inside the bag.

In another experiment, all individuals of *Sitophilus zeamais Motschulsky* were dead at 46 days of storage in plastic bags, at CO_2 and O_2 concentrations of 13.7% and 4.8%, respectively (Santa Juliana and Casini, unpublished data, 2008).

The direct causes of the mortality of insects exposed to modified atmospheres are still not fully understood. Several authors have studied the toxic effects of the modification of atmosphere gas concentration and found that modified atmosphere acts on desiccation, because spiracles remain open and therefore insects do not regulate water loss. It also acts on energy metabolism due to depletion of triglycerides as substrate (Donahaye, 1991), and acidification at cellular level that may lead to an interruption of vital reactions (Adler, 1993, 1994). Navarro and Friedlander (1975) found that an increase in CO_2 concentration increased hemolymph lactate levels. These authors detected that lactate levels increased rapidly as oxygen level decreased to values near 3%.

Another study reported that under the effects of anoxia (low O_2 concentration) glucose levels decrease; when anoxia and hypercarbia (high CO_2 concentration) combine, citrate levels fall (Friedlander and Navarro, 1979a, b). Another consequence of the effect of anoxia and hypercarbia is inhibition of the Krebs cycle. Calderón and Barkai-Golan (1990) found a synergistic effect of the combination of anoxia and hypercarbia, eggs dying first, then larvae, adults and finally pupae. Control of pupae starts at a CO_2 concentration of 15% (Banks et al., 1990).

Effectiveness of insect control by means of modified atmosphere depends on several factors, such as temperature, relative humidity of intergranular air and atmospheric concentration of gases, as it was mentioned earlier. Other equally important factors are the species controlled, pest development stage, and time of exposure. Airtight condition of the storage system is important in relation to time of exposure, not only to achieve a minimum CO_2 concentration necessary for control of all stages but also to maintain that concentration over time, thus increasing effectiveness of control and avoiding grain quality deterioration.

4. CONCLUSIONS

The inclusion of screened tubes containing materials that induce an increase in CO_2 concentration and a reduction in O_2, both gases that make up the intergranular atmosphere, was effective for an absolute control of insect pests using an organic procedure. Indeed, in a short period, CO_2 and O_2 concentration was substantially modified, remaining stable for a long time. Control effectiveness increased with time of exposure.

The inclusion of chopped corn forage to modify CO_2 and O_2 concentration was effective and appears as an economic alternative to small farmers. Small farmers also have the possibility of using other types of materials that modify CO_2 concentration, depending on availability of such materials in their areas.

To achieve an effective gas concentration at a minimum necessary time of exposure high hermetic conditions in storage should be ensured, such as those obtained in this work using low-density polyethylene.

It should also be noted that, while it was not an objective of this study, modification in the concentration of intergranular atmosphere is beneficial not only because of the control on insects but also because it has effects on fungi present in the grains and that are the main cause of damage in grain quality, affecting grain growth and mycotoxin development.
The method studied proved to be an efficient, environmentally friendly, and non-contaminating method that preserved quality of corn grains during storage. This is especially important because most of the corn stored by small farmers is directly used for consumption by rural families.

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