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Pest control treatments with phosphine and controlled atmospheres in silo bags with different airtightness conditions

Bárbara Carpaneto [a], Ricardo Bartosik [a, b, *], Leandro Cardoso [a], Pablo Manetti [c]

[a] National Institute of Agricultural Technology (INTA), Argentina
[b] CONICET, Argentina
[c] Agronomy College, Mar del Plata National University, Argentina

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A B S T R A C T

The silo bag technology has been extensively used in Argentina for storing grains (e.g. wheat, corn, barley, sunflower and soybean among others) since the mid-1990s. Silo bag are widely considered a hermetic storage system in which PH_3 fumigation is frequently implemented for pest control. However, there is insufficient information regarding the potential airtightness of silo bags and how it could affect the performance of fumigation and controlled atmosphere treatments. In this study, a pressure decay test (PDT) was implemented to characterize airtightness level of silo bags set up following various procedures. PH_3 fumigation treatments with different dosages and hermeticity levels were conducted, and fumigant concentration was monitored. Controlled atmosphere treatments with carbon dioxide were also implemented in silo bags with different hermeticity levels. Results showed that less than half of the bags tested in the field had a PDT indicated for fumigation (90 s), and that when a bag without thermo sealing was used for fumigation, this treatment failed. However, it was demonstrated that with simple and inexpensive practices silo bags can achieve high enough airtightness conditions to implement successful PH_3 fumigation (5 days above 200 ppm with a dosage of 1 g of PH_3/m^3) and even controlled atmosphere treatments (more than 18 days with CO_2 concentration above 70%). This study shows that silo bags could be used as a cost competitive hermetic storage technology for performing controlled atmosphere treatments.

1. Introduction

The silo bag technology has been extensively implemented in Argentina for storing grains (e.g. wheat, corn, barley, sunflower and soybean among others) since the mid-1990s (Bartosik, 2012). During the last 5 years a total of 40–45 million tons of different grains have been stored every year in this flexible hermetic system. Today, the silo bag technology is being implemented in more than 50 countries improving postharvest logistics and reducing grain postharvest losses.

Silo bags are considered hermetic storage systems. However, when dry grain is stored in silo bags the resulting biological activity is low, and hence, the degree of modification of the internal atmosphere is not sufficient to generate a lethal environment for insects (CO_2 concentration less than 10% and O_2 concentration above 10%) (Abalone et al., 2011; Arias Barreto et al., 2013; Bartosik et al., 2008; Cardoso et al., 2008; Rodríguez et al., 2008).

Nevertheless, insect development could be affected in this semi-restricted environment (Subramanyam et al., 2012). In many countries there is a legal restriction for trading grains with live insects (i.e. nil tolerance), implying that a pest control treatment has to be implemented in most of the grain at some point of the commercialization chain. When silo bags are used for storing grains, the preferred pest control treatment is phosphine (PH_3) due to the potential airtightness of the bag. For the same reason, controlled atmospheres (CA) treatment could be a suitable control method.

In Argentina, the fumigation of silo bags with PH_3 could be done right after the harvest when the bag is loaded, or after 3–8 months of storage in the field (in this case the hermeticity of the bag could be compromised (Darby and Caddick, 2007). The tablets of aluminum phosphide are inserted every 5–10 m along one side of the bag, with a dosage from 1 to 2 g of PH_3 per t, regardless the type

* Corresponding author. Current address: Ruta 226 km 73,5, Balcarce, 7620, Argentina.
E-mail address: bartosik.ricardo@inta.gob.ar (R. Bartosik).

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of grain (equivalent to 0.75–1.5 g/m^3 for wheat) and the hermeticity level of the bag. No particular care is taken regarding the sealing of the end of the bag, and most of the time the bag is closed by folding the plastic cover on itself and adding some weight on top. Hermeticity of silo bags is not tested and it is difficult to predict beforehand. As a result, fumigant leakage is not considered for prescribing the initial dosage. PH_3 concentration is not measured during treatment and fumigators just assume that the procedure accomplishes the Argentine standard for effective PH_3 fumigation, which is 200 ppm for 5 days, although sometimes it might not be accomplished.

On the other hand there is an increasing demand for grains free of pesticides residues. The silo bag technology has the potential to be used for CA treatments by injecting CO_2 or N_2 and maintaining a critical concentration during a certain period of time.

Research has been done regarding the effect of hermetic storage in silo bag on grain quality, mold and micotoxin development, early detection of spoilage, economics and logistics, and modeling of the internal environment, which were summarized by Bartosik (2012). In addition, research has been done on control of pests with PH_3 in silo bags (Cardoso et al., 2009; Darby and Caddick, 2007; Ridley et al., 2011), but the documented experiences did not explore in detail the relationship between a successful PH_3 treatment and the airtightness level of the silo bag. Additionally, the airtightness level required for CA treatment is higher than that required for PH_3 fumigation (Navarro, 1998), and there is insufficient information on whether the silo bags can achieve enough hermeticity to implement a successful CA treatment (Darby and Caddick (2007) performed PDT in few silo bags in the field with, in general, unsatisfactory results). One of the main limitations for implementing CA treatments at a large scale is the cost of airtight bins. If the silo bag can be airtight enough for CA treatment, they could be successfully used as an inexpensive technology for CA treatments.

The objectives of this study were 1) to characterize the airtightness of silo bags placed in the field; 2) to evaluate the efficacy of a PH_3 fumigation treatment in silo bags with different dosages and hermeticity levels; and 3) to evaluate the feasibility of implementing a successful controlled atmosphere treatment in silo bags.

2. Materials and methods

2.1. Silo bags hermeticity assessment

A pressure decay test (PDT) adapted from Darby and Caddick (2007) was carried out in 21 silo bags placed in different farms and grain storage facilities in Southeast of Buenos Aires province, Argentina. Silo bags are made of three layers liner (230 μm thickness with UV protection) with a diameter of 2.74 m and from 20 to 60 m long, holding approximately from 70 to 200 t of wheat, corn and soybean, and up to 120 t of sunflower. The PDT consists of generating a negative pressure inside the bag (i.e. −1200 Pa) with a fan, and measuring the time it takes to drop to half of the initial negative pressure (i.e. −600 Pa). Approximately at the center of the silo bag, a pipe of 40 mm diameter was inserted 0.8 m inside the grain mass. The edge of the plastic cover, in the perforation made to insert the pipe, was sealed to the pipe with silicon sealant and tapes, so hermeticity was not affected by the inserted pipe. The outside end of the pipe had a valve that can hermetically close the connection between the inside atmosphere of the bag and the outside. The valve was connected to a centrifugal fan (Chicago Blower, 0.33 HP, USA) through a flexible plastic hose of 40 mm diameter. The pressure was monitored with a digital pressure gauge (Sper Scientific, China) connected to the bag by a plastic tube of 5 mm diameter, and the time from −1200 Pa to −600 Pa was recorded with a chronometer (Fig. 1).

2.2. PH_3 fumigation treatments

Five standard silo bags of 2.7 m diameter and from 20 to 60 m long holding wheat (T1, T2 and T5) and sunflower (T3 and T4) were used to perform the fumigation trials. The wheat silo bags were placed in farms close to Balcarce, Buenos Aires province, Argentina, and the sunflower silo bags were placed at the Cargill oil crushing facility near Quequen port, Buenos Aires province, Argentina.

The silo bags corresponding to T1 to T4 were made without any particular care to preserve the hermeticity of the system, representing the most common conditions in which fumigation is performed in silo bags. It means that no soil preparation was done to limit the risk of perforation by stones or other hard objects, and the end of the bag was folded over and some weight was added on top. On the other hand, the bag used for T5 was thermo sealed at the ends directly in the field with a portable sealing equipment (La Pipiola, Argentina), enhancing the potential hermeticity of the bag. Thermo sealing is a simple and affordable practice to be implemented by farmers and local elevators.

Grain samples were collected before the fumigation trials from 5 locations along the bag with a standard probe and moisture content (m.c.) was measured with a moisture meter (Dickey John, Gac 2100, USA). The wheat silo bags (T1, T2 and T5) were filled with recently harvested grain, with m.c. between 12.8 and 13.4%. The sunflower silo bags (T3 and T4) were filled with recently harvested oilseeds with m.c. around 11%. Grain temperature was measured before and after the fumigation trials by inserting in the bag a temperature probe in 5 locations (Cereal Tools, Temperature Probe, Argentina). In all treatments the temperature was between 20 and 25 °C.

The fumigation product was aluminum phosphide tablets of 3 g (Phostoxin, Degesch, Germany) that produces 1 g of PH_3. The dosage was from 0.75 to 1.72 g PH_3/m^3 (Table 1), and the expected maximum theoretical concentration (MTC) ranged from 1100 to 2500 ppm, approximately (see Section 2.2.1 for MTC computation).

The aluminum phosphide tablets were inserted in the grain mass every 5 m along the bag, thus the PH_3 gas should move in the horizontal direction 2.5 m to each side of the application point at the most. For instance, for T1 the total length of the bag was 60 m, so 12 application points were considered in the total length of the bag. The first application point was located at 2.5 m from the beginning of the bag. In each application point the amount of tablets inserted were related to the volume of grain contained in between two applications points. Considering that a 60 m long bag holds 260 m^3 of wheat, a section of 5 m contains 21.5 m^3, implying that for T1 a total of 16 tablets were inserted in the grain mass in each application point (16 g PH_3/21.5 m^3 = 0.75 g/m^3).

A plastic tube of 40 mm in diameter was introduced diagonally toward the center and bottom of the grain mass and the tablets were placed inside, with the precaution of spreading the tablets throughout the profile of the grain mass in each application point. This was achieved by lifting of the plastic tube a few centimeters after dropping some tablets. The contact between the aluminum phosphide tablets and the plastic cover was avoided by leaving a layer of grain in between the tablets and the plastic cover to prevent an eventual damage of the plastic cover during the exothermic reaction of the tablets when releasing the gas.

The measurement of gas concentration was made with a hand pump and colorimetric tubes (Drager, Lubeck, Germany – accuracy ±10% *SD*). The measurement was performed every 1–2 days from application at the closing end of the silo bag, in between application points and at the application point.

2.2.1. Maximum theoretical concentration

In order to quantify the evolution of PH_3 concentration in relationship to the initial dosage, the maximum theoretical