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Testing of an inexpensive modified atmosphere chamber for small farmers using soaked grain as oxygen scavenger

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Abstract

Insects are one of the major causes of grain losses. Fumigation methods or controlled atmosphere (CA) treatments usually require sophisticated technologies that are not affordable in subsistence farming. This study focused in testing an inexpensive and effective modified atmosphere (MA) chamber using standard liners and soaked grain as O_2 scavenger. Freshly harvested wheat (14% m.c.) was bagged in 35 kg plastic raffia bags (non-hermetic). A stack of 13 bags was assembled inside a polyethylene liner of 70-micron thickness and dimensions of 1.0 m x 1.0 m x 1.8 m. The liner was closed by twisting, folding, and tying the opening with a rope. The airtightness was tested by a pressure decay test (PDT). Four treatments were evaluated, including a control (only dry grain) and three treatments with soaked grain as oxygen scavenger. Oxygen and CO_2 concentrations were measured with a portable gas analyzer. Results indicated that the respiration rate of soaked grain was 120 to 150 times greater that that of dry wheat. The incorporation of a small quantity of soaked grain as oxygen scavenger (1% dry matter) resulted in a reduction of the oxygen concentration to less than 2%, creating a lethal atmosphere for insects. The PDTs of the chambers were from 0.15 to more than 19 min. The variability in the final O_2 and CO_2 concentration achieved in all the treatments was quite low in spite of the variability of the PDT. This would suggest that the effect of incorporating oxygen scavengers was of a much larger magnitude than the differences in airtightness observed. This study demonstrated that an effective MA chamber can be created using standard 70-micron polyethylene liner, a simple sealing method and sacrificing only small portion of soaked grain as oxygen scavenger.

Keywords: Hermetic storage, Pest control, Subsistence farming, Plastic liner, Modified atmosphere, Wheat, Sealing method

Introduction

Insects are one of the major causes of grain losses in developing countries. Fumigation with phosphine is the most widely implemented insect control treatment in grains and non-perishable products (Agrafioti et al., 2020). However, it requires the manipulation of hazardous material (Bell, 2000), such as aluminum phosphide pellets, and there is a risk of development of resistance (Nayak et al., 2020). Controlled and modified atmospheres (CA/MA) under hermetic storage are suitable alternative treatments, with the benefit that there is no hazard for the user, it does not leave residue of pesticide in the grain and there is no development of resistance. However, to obtain full benefit of the hermetic storage it is required to achieve a low O_2 concentration (below 2%) or high CO_2 concentration (above 20%) (Navarro et al., 2012).

During MA treatment, the gas concentration inside the hermetic container is the result of the balance between the respiration rate of biotic agents (grains, fungi and insects) and the gas exchange rate with the outside (permeability and leakage) (Bartosik, 2012) and CO_2 sorption of the grain. Implementing MA storage in dry products, such as grains, implies an extra challenge. Non-perishable dry products typically have a low respiration rate. When the grain is dry and the initial insect population is low, the modification of the internal atmosphere by the respiration of the biotic agents inside the grain is insufficient (exchange rate higher than respiration rate) (Abalone et al., 2011a, 2011b). In this case, only when the insect population develops up to certain level, the O_2 consumption rate overpasses the O_2 entrance rate through the liner permeability, and the internal gas composition changes substantially. However, this process leads to grain quality losses before the critical atmosphere is achieved. The use of liners with gas barrier (i.e., EVOH) improves the effectiveness of hermetic storage systems, since gas leakage is reduced and a higher and faster modification of the internal atmosphere is achieved (Cardoso et al., 2016). However, liners with gas barrier are expensive and it might not be affordable for small farmers. Additionally, the use of liners with an O_2 barrier must be complemented with highly efficient sealing systems. One alternative is to incorporate O_2 scavengers to compensate the higher permeability of a standard polyethylene liner and the extra gas leakage of a simple sealing method. Taher and Bartosik (2018) proved that this concept could work in a MA system of 0.70 m^3 using a standard 70-micron polyethylene liner and soaked soybean as O_2 scavenger. However, in that study, the MA chamber was heat sealed. This sealing technology is quite expensive and might not be available in most rural areas. To successfully transfer this technology to small farmers an integral solution should be found. Thus, in the present study, a simple and inexpensive MA system made of a standard polyethylene liner, using soaked grain as an oxygen scavenger and sealed with a simple method, was evaluated for creating a lethal environment for insects.

Methodology

Respiration experiment

A sample of 45 kg of wheat (same as used in the MA treatment described below) was divided into three sets of 15 kg each to obtain three different wheat conditions: 1) whole wheat, dry; 2) whole wheat, soaked; and 3) grinded wheat, soaked. For the condition 1, the wheat was used as it came from the field. For the condition 2, the sample was divided in four sub-sets of 3.6 kg each, placed in plastic trays and independently soaked in 5.0 L of distilled water for 60 min. The soaked grain was then transferred to a perforated metal tray to drain the remaining water for 60 min.

For the condition 3, the wheat sample was also divided into four sub-sets of 3.6 kg each and grinded with an electric mill (Foss, Cyclotec, CT 293, Denmark). The grinded wheat was soaked following the same procedure as described for condition 2. All samples were stored in hermetic plastic containers for 24 h until the setup of the respiration experiment. The moisture content (m.c.) determined with the oven method (19 h at 130°C) by triplicate (ASAE, 2003) was 14.3, 28.0 and 56.0% for the dry, soaked, and grinded-soaked samples, respectively. The following day, for each grain condition, 12 samples of 300 g of product were placed in Erlenmeyer flasks of 560 mL capacity and hermetically sealed with a rubber cap. Previously, a septum was inserted in the center of the cap to measure the internal gas composition with a needle connected to the measuring device (Checkmate, Dansensor, Denmark). The volume of the void space of the Erlenmeyer flasks (interstitial air and headspace) containing wheat at different m.c. was determined by measuring the volume of distilled water that filled it (Weinberg et al., 2008), and was 366, 362 and 345 mL for dry wheat, soaked wheat and grinded-soaked wheat, respectively. Immediately after closing the Erlenmeyer, internal gas composition was measured and four replicates of each wheat condition were placed in temperature-controlled chambers at 20, 25 and 30°C. The internal gas composition was measured again after 90 min for the soaked and grinded-soaked samples, and after 24 h for the dry wheat samples. The respiration rate based on CO_2 generation and O_2 consumption was calculated as described by Ochandio et al. (2017).

Controlled atmosphere treatments

The wheat used in this study was harvested at 14% m.c. in December 2019 at INTA Balcarce Research Station (Balcarce, Buenos Aires, Argentina) and bagged in 30 kg polypropylene raffia bags (non-hermetic). Six MA chambers were made with a tubular polyethylene liner of 70-micron thickness and dimensions of 1.0 m x 1.0 m x 1.8 m, and heat-sealed at the bottom end. These plastic bags are widely available, inexpensive (about 3 USD), and are placed in the interior of the raffia big-bag for transportation of bulk construction material, such as sand. Thirteen raffia bags filled with dry wheat were placed inside each MA chamber, containing a total of 390 kg of grain per chamber (335 kg dry matter (DM)). The chamber was closed by twisting and folding the open end and tying it with a rope (Fig. 1). The dimension of the sealed MA chamber was 1.0 m x 1.0 m x 0.6 m. Each MA chamber was assembled on a wooden pallet covered with a foam sheet to protect the liner, and stored at the INTA Grain Postharvest Pilot Plant at Balcarce Research Station. Four treatments were evaluated considering three replicates (chambers) per treatment. The treatments were arranged in two consecutive trials of two treatments each. Treatment 1) only dry grain (control); Treatment 2) 1% DM of Grinded-Soaked wheat as oxygen scavenger; Treatment 3) 1% DM matter of Whole Soaked wheat as oxygen scavenger; and Treatment 4) 0.5% DM of Whole Soaked wheat as oxygen scavenger. The procedure for soaking the grain was similar to that described above.

Trial 1

The six MA chambers were divided in two groups of three. In Treatment 1 control, the chambers were closed to study the evolution of the internal gas concentration created by the dry wheat only. In Treatment 2, two plastic containers (0.35 m x 0.20 m x 0.12 m) filled with the equivalent of 3.35 kg DM of grinded-soaked wheat (or 1% of the grain dry mass in the stack) were incorporated as oxygen scavenger in each chamber. The airtightness of the sealed chamber was tested with the pressure decay test (PDT). Briefly, a vacuum pump (Dosivac, DV 95, Argentina) was connected to the sealed chamber through a previously incorporated valve in the liner.

After a negative pressure of 1200 Pa was generated, the valve was closed and the time that it takes for the internal pressure to drop from -1200 to -600 Pa was recorded (Navarro, 1998). Oxygen and CO_2 concentrations were measured once or twice per week with a portable gas analyzer (CheckPoint, Dansensor, Denmark) through a rubber septum previously inserted in the liner of the chamber.

Fig. 1. Sealing method of the modified atmosphere chamber. Left: opening of the bag twisted; Center: close-up of knot sealing the modified atmosphere chamber; Right: detail of a sealed chamber with the oxygen scavenger inside.

Trial 2

After finishing the treatments of Trial 1, the chambers were opened and ventilated. The six CA chambers were divided in two groups of three. In Treatment 3, two plastic containers filled with the equivalent of 3.35 kg DM of whole soaked wheat (or 1% of the grain dry mass in the stack) were incorporated as oxygen scavenger in each chamber, and in Treatment 4 one plastic container filled with the equivalent of 1.68 kg DM of whole soaked wheat (or 0.5% of the grain dry mass of the stack) was incorporated. The MA chambers were sealed, and the PDT was performed in the same way as explained for Trial 1. Oxygen and CO_2 concentrations were measured once or twice per week with a portable gas analyzer (CheckPoint, Dansensor, Denmark).

Results and discussion

Respiration Rate

In terms of CO_2 release, the soaked wheat respires from 115 to 150 folds more than the dry wheat, and the grinded-soaked wheat respires from 2.5 to 7.9 folds more than the soaked wheat. In terms of O_2 consumption, the soaked wheat respires from 120 to 150 folds more than the dry wheat, and the grinded-soaked wheat respires from 1 to 3.3 folds more than the soaked wheat. This implies that 1 kg DM of grinded-soaked wheat releases an amount of CO_2 equivalent from 400 to 1000 kg of dry wheat (depending on temperature), and consumes an amount of O_2 equivalent from 130 to 490 kg of dry wheat. Taher and Bartosik (2018) reported a higher respiration rate of soaked soybean (6950 mg CO_2/(kg DM day) and 7400 mg O_2/(kg DM day)) in comparison with the respiration of soaked wheat reported in this study.

Table 1. Carbon dioxide and oxygen respiration rates (mg/(kg DM day)) of wheat at different conditions and incubation temperatures. Values are average of four replicates (SD between brackets).

Grain condition	Temperature (°C)					
	20		25		30	
Dry (CO_2)	6	(3)	10	(6)	11.5	(9)
Soaked (CO_2)	755	(152)	1149	(112)	1682	(132)
Grinded-soaked (CO_2)	5960	(427)	4122	(60)	4236	(41)
Dry (O_2)	-6	(2)	-11	(4)	-13	(4)
Soaked (O_2)	-883	(193)	-1341	(69)	-1753	(152)
Grinded-soaked (O_2)	-2923	(180)	-1432	(26)	-2253	(26)

Pressure decay test

Table 2 shows the results of the PDT of the six grain MA chambers in trials 1 and 2. It can be observed that the PDT results were widely variable, from 15 s to more than 19 min. According to Navarro (1998), an hermetic structure 95% full should have a PDT of 3 min to be suitable for CA treatments and 5 min for MA storage. Based on this classification, in Trial 1 all chambers (except 3 and 4) accomplished the threshold of 5 min and could be suitable for MA treatments. After performing a failed PDT in chambers 3 and 4, the sealing procedure was repeated and a new PDT was conducted, but the results did not change. This would imply that most likely the liners of these two chambers had undetected leaking. In Trial 2 the results of the PDT were, in general, lower than in Trial 1. However, it was not possible to identify the causes of the lower PDT in the second trial. Based on these results, the twisting and folding sealing method could have the potential to achieve suitable airtightness levels for CA/MA treatments.

Table 2. Pressure decay test for the modified atmosphere chamber expressed as minutes to drop the internal pressure from -1200 Pa to -600 Pa.

Trial	Modified Atmosphere Chamber					
	1	2	3	4	5	6
1	> 5	> 5	0:30	2:30	> 5	> 5
2	1:15	> 3	0:15	2:40	> 5	> 5

Gas concentration inside the MA chambers

In Treatment 1 (Control) (Fig. 2), the CO_2 and O_2 concentrations after 20 d resulted in a small change of less than 1 percentage point (0.6% CO_2 and 19.9% CO_2). Clearly, this internal atmosphere would not be able to prevent pest development. In contrast, the treatments with the O_2 scavenger (Treatments 2 to 4) resulted in a substantial modification in the internal atmosphere. The treatment with 1% DM of grinded-soaked wheat quickly modified the internal atmosphere, tending to stabilize after 20 d of storage to about 5% of O_2 and CO_2 concentrations (Fig. 2).

Treatment 3 (Fig. 2) with 1% DM-soaked whole wheat had a lower rate of modification in the internal atmosphere in comparison with Treatment 2, grinded-soaked wheat, but in the long term stabilized in a lower O_2 concentration (1.7% after 50 d). Treatment 4, with 0.5% DM of whole and soaked wheat, also resulted with a substantial modification in the internal atmosphere. However, the O_2 concentration stabilized at about 4%, double as in Treatment 3, insufficient for achieving a lethal atmosphere.

The variability in the final O_2 and CO_2 concentration achieved in all the treatments was quite low (see error bars in Fig. 2) in spite of the different PDT of the different chambers. This would suggest that the effect of incorporating oxygen scavengers was of a much larger magnitude than the differences in airtightness observed. The amount of soaked grain that had to be sacrificed as oxygen scavenger is certainly a small portion of the total. In this study, 1% DM of the total grain mass was enough to compensate for the O_2 leakage. In a previous study Taher and Bartosik (2018) used soaked soybean seeds as oxygen scavenger and determined that a lethal environment could be achieved sacrificing about 0.5% DM.

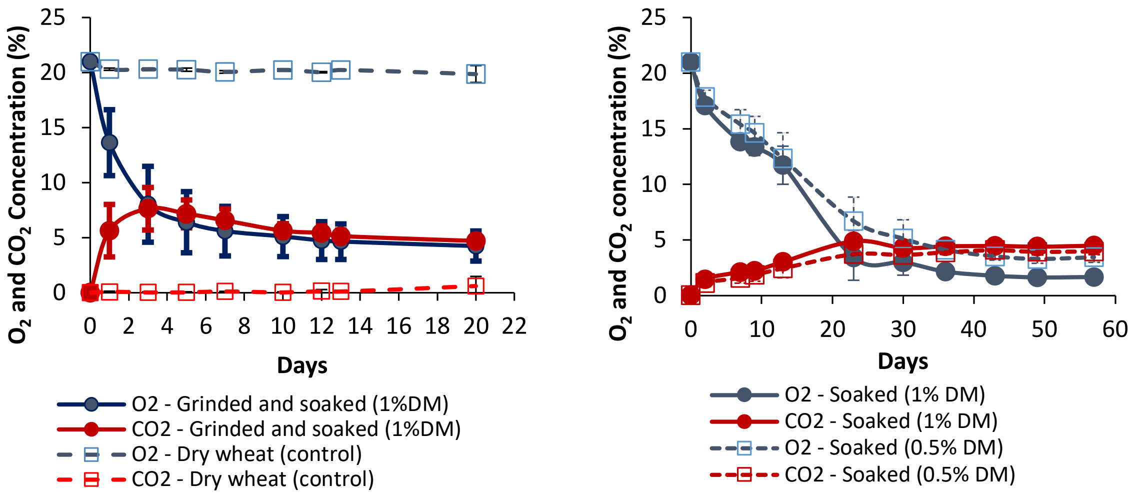

Figure 2. Average concentration of oxygen and carbon dioxide for Treatment 1 (control - only dry wheat) and Treatment 2 (1% DM of grinded-soaked wheat) (left); and for Treatment 3 (1% DM of soaked whole wheat) and Treatment 4 (0.5% DM of soaked whole wheat) (right). Error bars indicate the SD of the measured concentration.

Conclusions

The incorporation of a small quantity of soaked grain as oxygen scavenger (1% DM) was a suitable technical solution for creating a lethal atmosphere in the hermetic storage of dry products. The simple method of sealing the chamber by twisting, folding and tying the liner with a rope resulted in an appropriated MA atmosphere. This solution was not only technically sound, but also practical and economical.

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