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Efficacy of Bio-CO_2 as a non-chemical fumigant on pest control in wheat storage

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Abstract

The study evaluated the viability of Bio-CO_2 as a fumigant on mortality of adult *Rhyzopertha dominica,* seed germination, and seed quality. Bio-CO_2 is a by-product of the compressed biogas/ bio-methane production plant, which constitutes CO_2 as a major component and some of CH_4 and H_2S at ppm level. Wheat grain (Variety: H.D.-3086, Lot No. IARI/SPU/FA19286) was used in the present study. Fifteen grain plastic bottles of diameter 8.2 cm, height 19 cm, and total volume of one litre each were taken for the study. The purging of Bio-CO_2 fumigant was carried out at 0.5, 1.0, 1.5, and 2.0 L/min. The insect mortality of 100% was found in 1, 3, and 5 d using Bio-CO_2 as fumigant at 80, 60, and 40% concentration, respectively. Purging of the bottles was done at a gas flow rate of 1.5 L/min. There were no significant differences in seed weight observed after a storage period of 60 d under the elevated CO_2 storage atmosphere. However, seed weight loss of about 5.0% in controlled and 17.3% in grain stored with *R. dominica* without fumigation were found. The seed germination was reduced from 96 to 87.5%, 96 to 88.5%, and 96 to 90% at 80, 60, and 40% CO_2 concentration, respectively. However, the minimum seed germination certified by the SPU, ICAR-IARI, New Delhi was 85%. Thus, Bio-CO_2 as a fumigant resulted in better insect control than pure-CO_2 with no significant seed germination and seed quality change over a two-month storage period.

Keywords: Fumigant, Waste gas, Carbon dioxide, Insect mortality, Grain quality, Seed germination

Introduction

Stored food grain insects are the major threat to dried, stored, durable agricultural commodities and many value-added products globally (Arora et al., 2020). Post-harvest losses include losses during various unit operations, e.g., harvesting, threshing, cleaning, storage, processing, and transportation (Kumar and Kalita, 2017). These losses are estimated to be about 9% in developed and 20% in developing countries (Arora et al., 2020).

Altogether, the total post-harvest losses worldwide, the storage losses of rice, wheat, and maize have been around 2.7-15.1%, 0.9-56%, and 0.2-11.3%, respectively. The pest infestations are solely responsible for grain losses of about 5-10% during its storage in developed and 30-40% in developing countries (Kumar and Kalita, 2017; Cao et al., 2019). Meanwhile, the food demand is estimated to be increased by 70-100% by the end of the year 2050 (Godfray et al., 2010; Hodges et al., 2011). Therefore, reducing the losses of food grains by insect attack during storage is a major global concern.

So far, popular chemical fumigants like carbon tetrachloride, ethylene dibromide, aluminium phosphide, sodium cyanide, methyl bromide and phosphine have been used to a large extent to control pest infestation worldwide (Mohan and Gopalan, 1992; Ozkara et al., 2016, Cao et al., 2019). These fumigants effectively control insect pest growth in grain bulk; meanwhile, their excessive use leads to human health and environmental problems and thus banned in various countries (Proctor, 1994; Cheng et al., 2012). Whereas, due to the negative impact on ozone layer depletion (Sande et al., 2011), the use of methyl bromide had also been withdrawn in 2015 (Meyer and Newman, 2020). Phosphine also has a possible carcinogenic effect on humans and is still under review in the American and European countries (Bell, 2000). Another chemical fumigant that is ethanedinitrile (cyanogen), has recently been used in wheat storage to control pest infestation. The highly sorptive nature of ethanedinitrile in grains limits its use as an effective fumigant in storage pest control (Ramadan et al., 2020).

Reduced oxygen and raised carbon dioxide environment are the most suitable alternative to chemical fumigants. Presently, the storage of grains under an elevated carbon dioxide environment is getting more attention globally (Cao et al., 2019). The use of carbon dioxide as a fumigant is safe as it does not leave any harmful residues and is effective in controlling all life stages of a wide range of pests (Riudavets et al., 2014). This study evaluated wheat storage under fumigation by waste gas (mixture of carbon dioxide dominantly, some methane, and traces of hydrogen sulfide) as a fumigant. It is the first study of grain storage under fumigation by waste gas from compressed biogas (CBG) plant at Biogas Laboratory, Centre for Rural Development and Technology, Indian Institute of Technology Delhi, India; however, some studies of grains stored under raw biogas are available (Palaniswamy and Dakshinamurthy, 1986; Mohan and Gopalan, 1992; Chanakya et al., 2015). The use of raw biogas as fumigant is not appropriate due to its high calorific value with potential applications in cooking/ thermal energy, or as engine and vehicular fuel (Deng et al., 2020). In addition, the moisture content of raw biogas could wet the grain also. Therefore, this study was conducted to determine the efficacy of Bio-CO_2 as fumigant for insect control and effect of Bio-CO_2 on grain parameters like seed weight loss, and germination.

Material and methods

The mortality of adult *R. dominica* was determined at 40, 60, and 80% carbon dioxide in the waste gas from the CBG plant in five bottles for each treatment filled with grain to 25, 50, and 75% of its volume in a preliminary study. The bottle with grain at desired concentration of CO_2 was kept inside a temperature-controlled chamber at 28 ± 2°C.

Method of insect rearing
The newly emerged *R. dominica* adults were collected from the Division of Entomology, Indian Agricultural Research Institute, New Delhi, India. The adults were transferred into a box covered with a muslin cloth and fed with a mixture of 250 g coarse wheat and 50 g wheat flour (Noomhorm et al., 2009). The moisture content of the diet was 12.3%. The suggested moisture content of grain for *R. dominica* rearing is about 12-14% (Edde, 2012). The box was kept in a temperature-controlled room at 28±2°C with 70% RH and a light to dark hours of 16:8 as reported to be the optimum conditions for its growth (Edde, 2012; Wong-Corral et al., 2013).

Source of non-chemical fumigant
The waste gas was obtained from the off-stream channel of the CBG plant. The plant was based on water scrubbing technology. The waste gas obtained comprised around 73.8-74.2% CO_2, 12.7-14.2% CH_4, 0.5-1.6% O_2, 795-1509 ppm H_2S, and 9.8-12.1% as a balance. To obtain 90% of Bio-CO_2 concentration, the plant was operated at 0.6-0.7 MPa, 25 m^3/h biogas flow rate, and 5 m^3/h water flow rate.

Method of experiment
Fifteen tapered experimental plastic bottles of diameter 8.2 cm, height 19 cm, and total volume of one litre each were used. A glass tube of the inner diameter of 0.3 cm and 15 cm length was used as a gas inlet, and a similar tube was used as an outlet. The inlet and outlet glass tubes were connected with a silicon tube and two-way stopcock at the end, as shown in Fig. 1. The inlet tube was inserted up to 14-15 cm depth from the top of the bottle through a rubber cork. There were three replicates at each CO_2 concentration of 80, 60, and 40% with adult *R. dominica*, three replicates with *R. dominica* adults without fumigation, another three replicates without R. dominica and without fumigation as control were used for 60-d storage study.

Fig. 1. The experimental set-up for Bio-CO_2 purging.

A simple analytical method was used to quantify the carbon dioxide purging by knowing the bulk density and true density of wheat grain. The bulk density of the selected wheat grain was determined according to the methodology adopted by Chandra et al. (2012). The true density was determined using the standard Toluene displacement method (Singh et al., 2010). After that, the total void spaces available from which air to be removed to get a desired carbon dioxide concentration was calculated as:

$$\text{Total void spaces} = [\{\left(1 - \frac{\rho_b}{\rho_t}\right) \times V_g\} + V_h]$$

Where P_b, P_t, V_g, and V_h represents bulk density (kg/m^3), true density (kg/m^3), volume occupied by grain (L), and headspace volume of the bottle (L), respectively.

Quantity of CO_2 purging = Total void space in the bottle filled with grain (L) × desired concentration of CO_2 (decimal).

Optimization of CO_2 flow rate at different grain-fill volume

A rotameter (Flowstar FSC-100, Flow Star Engineering Pvt. Ltd., Faridabad, India), especially for carbon dioxide, was used to optimize the flow rate to achieve the best purging efficiency. The rotameter measured a flow rate of 0.5-10 L/min with the least count of 0.5 L/min. The trials with 0.5 to 2.0 L/min were carried out in the bottles filled with grains. A total of ten replications at each flow rate were carried out to get the best uniformity of carbon dioxide and purging flow rate. Best purging efficiency was achieved at 1.5 L/min (data not reported).

The purging efficiency of the grain bottle was determined by assuming the free mixing of carbon dioxide in the air (Mann et al., 1999).

Insect mortality test

The mortality was checked after 24, 48, 72, 96, and 120 h. Before the Bio-CO_2 fumigation, the bottle was filled up to one-fourth, half, and three-fourth with grains infested with 20, 50, and 70 adults of *R. dominica*. The insect mortality was checked according to the methodology reported by Noomhorm et al. (2009) and Riudavets et al. (2009).

Analysis of thousand-seed weight and germination

The Alberta seed testing standard (2016) was used to measure the thousand-seed weight and germination. The seed weight and germination were evaluated after a storage period of 60 d under Bio-CO_2 fumigation to determine any losses due to insect attack.

Results and discussion

Physical characteristics of grain and quantity of carbon dioxide purged

The bulk and true density of the wheat grain were 804.8 kg/m^3 and 1266.4 kg/m^3, respectively. The void space present in the grain was 36.5%. The quantity of carbon dioxide purged at different concentrations and grain-fill volumes is presented in Table 1.

Table 1. Quantity of carbon dioxide purged at 1.5 L/min flow rate to grain-fill volume

Grain-fill volume	Total void space[a] (L)	Quantity of CO_2 purged at different concentrations (L)		
		40%	60%	80%
25%	0.84	0.34	0.50	0.67
50%	0.68	0.27	0.41	0.54
75%	0.52	0.21	0.31	0.42

[a]Void space in grain + headspace volume.

The fumigant concentration was checked every 24 h using a portable biogas analyzer (Biogas 5000 Geotech, Netherland). The concentration of CO_2 in the storage bottles varied within ±2% from the desired concentrations. Loss of around 12.9-22.4% concentration occurred in 24 h, which was replenished regularly.

Insect mortality

To get 100% mortality of *R. dominica* 5, 3, and 1 d was sufficient at 40, 60, and 80% of CO_2. Riudavets et al. (2009) found 100% adult mortality of *R. dominica* at 8 and 4 d at 50 and 90% CO_2 at 25°C, respectively. Kaliyan et al. (2007) also reported the storage of grain under pure CO_2 at atmospheric pressure and storage temperature above 21°C; around 9, 11, and 17 d were enough to control pest infestation at 80, 60, and 40% CO_2, respectively. Our study showed that waste gas from the CBG plant gave better result than the previous studies.

Effect of bio-CO_2 fumigation on seed weight and germination

The grain storage bottles had no insects within 1-5 d at 40-80% CO_2. Therefore, no significant weight loss of wheat was observed after a 60-d storage period. The grain stored in the controls had a weight loss of about 5.0% due to pest multiplication. The highest loss of 17.3% was observed with the infestation of *R. dominica* without fumigation. Similar findings were reported by Mekali et al. (2013). After a 60-d storage under CO_2 fumigation using waste gas, the seed germination was reduced by 6, 7.5, and 8.5% with 40, 60, and 80% CO_2, respectively. The results were in agreement with the findings of Mitsuda and Yamamoto (1980). The effect might also be due to the presence of methane and traces of hydrogen sulfide in the waste gas used as a fumigant. Also, the germination of legume seed (pigeon pea) stored under biogas fumigation remained unaffected (Anonymous, 1992). It might be unchanged because of a short storage period.

Conclusions

The use of waste gas from a compressed biogas plant showed better efficacy in insect mortality than the previously reported studies based on pure CO_2. Some CH_4 and H_2S in waste gas might have a supplementary lethal effect on insects. No significant differences were found in the seed germination over a 60-d storage period. Furthermore, the viability of such fumigants needs to be evaluated in a larger scale storage system for long-term storage under actual field conditions. The future study should also assess the suitability of waste gas as a fumigant on other grain parameters like nutritional quality, sensory evaluation. The efficacy of waste-gas as a fumigant could also be checked with other pests and grains.

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