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Potential of monitoring carbon dioxide to detect insect infestation in a wheat bulk

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Abstract

Monitoring carbon dioxide (CO_2) concentrations in a bulk of grain has been considered for detecting insect infestation. To evaluate the potential of monitoring CO_2 concentrations to detect insect presence at different bulk depths, in relation to changing temperature under aeration, a trial was carried out in Israel in a concrete bin of 180 tonnes containing wheat of 11.6% moisture content. Samples of wheat were taken from depths of 1, 3, 5, 7 and 9 m, thermocouples and gas sampling tubes were inserted to the same depths. Examination of wheat samples indicated presence of initial infestation in mid-June from average of 0.15 live insects per kg wheat to 2.05 live insects per kg wheat in March. In April live insects per kg wheat dropped to 0.8, probably due to the low temperatures achieved in the grain bulk. The observations lasted ten months during which aeration was performed intermittently to reduce the temperature of the grain bulk from initial 28.3°-34.8°C in June to 16.5°-20.0°C in March. Carbon dioxide concentrations were measured at all sampled depths and they varied from close to undetectable levels at initial samples to up to 9% when wheat temperature dropped to 20°C in March. Carbon dioxide concentrations progressively increased with the increase in insect populations. Although the bin was not sealed and no sealing operations were performed, CO_2 concentrations were detectable. A peculiar observation indicated that increase in CO_2 concentrations occurred in gas samples after aeration was cessed. The authors have no reasonable explanation for this observation. Insect populations consisted of *Tribolium castaneum* (Herbst), *Sitophilus oryzae* (Linnaeus), *Rhyzopertha dominica* (Fabricius) and *Oryzaephilus surinamensis* (Linnaeus). The initial low insect populations correlated well with low CO_2 concentrations. Whereas, the increased CO_2 concentration was affected by additional factors like level of gas tightness of the bin, temperature gradients and forced aeration.

Keywords: CO_2 monitoring, Insect infestation, Detection, Wheat, Grain bulk, Aeration

Introduction

To determine the presence of insects in bulk stored grain, manual samples, traps, and probes have been used. Manual inspection has been based on sieving, cracking-floatation and Berlese funnels to detect insects in grain bulks. Since these methods are time consuming, alternative detection methods like acoustic detection (Mankin and Hagstrum, 2012), CO_2 measurement, uric acid measurement, near-infrared spectroscopy, and soft X-ray methods have been proposed to the industry. The advantages and limitations of these insect detection methods have been evaluated by Neethirajan et al. (2007).

Several scientists have used CO_2 as an indicator of insect infestation (Howe and Oxley, 1952; Calderon and Shayya, 1961) or microbial infection (Steele et al., 1969; White et al., 1982) or both (Muir et al., 1980). Sinha and Wallace (1977) measured CO_2 concentrations in and around a small column (0.6% of total bulk) of spoiling rapeseed at 11 to 13.5% moisture content in a 46 tonnes bulk of dry rapeseed at 8.5 to 9.4% moisture content. Concentrations of CO_2 in the spoilage pocket were up to 2%. Measurements of CO_2 in a 27-tonnes cone-shaped pile of wheat placed directly on the ground without a cover indicated that CO_2 did not diffuse rapidly out of the grain bulk (Muir et al., 1980). Singh et al. (1983) mathematically modelled dispersion of CO_2 from three possible spoilage areas in a grain bin (6 m in diameter filled with wheat to 4.6 m height) and concluded that a CO_2 sensor with a resolution of 2 g/m^3 (0.1%) located near the center of the bin could detect grain spoilage when spoilage location is not known.

Ileleji et al. (2006) employed commercial CO_2 sensors near the vents and exhaust air stream of fans in the grain bin for measuring CO_2. They concluded that hot spots and early spoilage of grain can be detected inside grain bin using CO_2 sensors.

Maier et al. (2006) studied elevated CO_2 levels in localized pockets of a grain mass caused by insects, fungi, and grain metabolism. The primary objective of the study conducted by Maier et al. (2006) was to monitor CO_2 levels for early detection of spoilage. The measured CO_2 levels ranged from 0.05% to 0.5% and higher levels of up to 2.5 % were recorded with a portable CO_2 monitor. Maier et al. (2010) in their work on monitoring carbon dioxide concentration for early detection of spoilage in stored grain reported the presence of heavy stored-product insect population of up to 27 live insects/kg of grain.

Bartosik et al. (2008) carried out periodic CO_2 monitoring of silo-bags holding about 200 tonnes of wheat for the early detection of biological activity and spoiled grain. A distinctive value of CO_2 for different MC grains was established, which represents the typical atmospheric composition for a silo-bag with and without spoilage.

Gonzales et al. (2009) examined use of relative humidity (RH), temperature, and carbon dioxide (CO_2) sensors for their suitability to determine adverse storage conditions of wheat. Wheat at approximately 11% MC was aerated with the air that passed through high-moisture grain conditioned to nominal MCs of 14%, 16%, and 18% (wet basis). Sensors monitored air conditions during the entire storage period. Aeration was provided over 3-h periods at rates of 5 m^{3}h^{-1} tonne^{-1} and 10 m^{3}h^{-1} tonne^{-1}. Carbon dioxide sensors were effective in indirectly detecting moist grain conditions due to the large amount of CO_2 generated from the wet grain. Carbon dioxide levels monitored at the exhaust of the aeration duct were generally adequate in determining adverse storage conditions. A detailed overview of the types of CO_2 sensors, their sensing mechanisms and characteristics covering different aspects of the CO_2 sensor technology has been synthesized by Neethirajan et al. (2009). Also, Neethirajan et al. (2010) developed a carbon dioxide sensor using polyaniline boronic acid conducting polymer as the electrically conductive region. The sensor was demonstrated for use in detecting spoilage in stored grain.

Jian et al. (2014) studied the interstitial concentrations of carbon dioxide and oxygen in stored canola, soybean, and wheat seeds under various conditions. Sum of CO_2 and O_2 concentrations were close to 21%-22% at most airtight storage times and within any crop.

Muir et al. (1985) tried CO_2 as an early indicator of stored cereal and oilseed spoilage. Concentrations of CO_2 were measured in 39 farm-stored bulks of wheat, rapeseed, barley and corn in Canada and U.S.A. Spoilage was confirmed by analyses of grain samples in 97% of the 34 bins having CO_2 concentrations greater than 0.03% of ambient air.

Taher et al. (2019) attempted to predict soybean losses using CO_2 monitoring during storage in silo bags. Based on their results, a correlation to predict grain losses was developed, which considered grain moisture and a predictor related to the CO_2 concentration at the silo bag closing end as independent variables.

Zhang et al. (2014) studied a site-directed CO_2 detection method for monitoring the spoilage of stored grains by insects and fungi in Chinese horizontal warehouses. The CO_2 produced by grain respiration was relatively low, and the activity of insect and mould significantly affected the CO_2 concentration in the bulk.

So far, the reports were concentrated on detection methods mostly on spoilage of grain and very few were only for detecting insect activity using CO_2. Grain respiration, fungal activity, and insect activity on CO_2 detection were extensively investigated. None of the studies focused to correlate insect infestation in relation to CO_2 detection inside the grain bulks. In addition, the changes in temperature that affect the convection currents that take place in large bulks and the influence of mechanical aeration on CO_2 retention has not been reported. Therefore, the present study was carried out to test the CO_2 concentrations that can be developed as a result of natural insect infestation in a vertical aerated silo containing dry wheat.

Materials and methods

Storage bin

The observations were carried out during 10 mo of storage in a concrete bin containing 180 tonnes of wheat. The bin was square 4x4 m and 14.5 m high with a hopper of 2 m height from the discharge hatch. The base of the hopper was equipped with an aeration tube of 20.5 cm diameter. The bin had a loading opening of 60x60 cm through which thermocouple sampling tubes were inserted and grain samples were taken. The bin was equipped with an aeration system capable to deliver 2.8 m^3/(h/tonne). The aeration was operated to deliver ambient air from the bottom of the bin and the fan was activated by a thermostat that selected the suitable ambient temperature for aeration. Number of hours of fan operation was registered by a time recorder located adjacent to the fan.

Wheat grain

The wheat stored in the bin was a local cultivar "Nanasit" having moisture content (wet basis) in the range of 10.5 – 12.6%. Wheat samples were taken using a Prob-A-Vac (Minneapolis, MN U.S.A.) grain sampler, a probe that used vacuum to sample stored grain. Grain samples of 1 kg were taken periodically from the depths of the grain bulk at 1, 3, 5, 7, and 9 m deep from the surface. Moisture content was electronically measured using Motomco Model 919 grain moisture meter (Paterson, New Jersey, U.S.A.) calibrated for the local grain cultivar. For identification of insect infestation, the grain samples were sieved through a standard USA mesh #10. The separated live and dead insects were identified and counted.

Measurement of temperature and gas

Thermocouples and gas sampling tubes were installed using the external tube of the Prob-A-Vac at the same depths as grain samples were taken (at 1, 3, 5, 7, and 9 m deep from the bulk surface). Grain temperature was measured on a weekly to bi-weekly basis. Ambient air temperature and relative humidity was recorded using a thermo-hygrograph that recorded data from inside a meteorological station located adjacent to the bin aeration fan.

Gas samples were taken from the indicated depths using gas sampling PVC tubes of 3 mm internal diameter. Gas samples were analysed using thermal conductivity meter (Gow Mac, Bethlehem, PA, U.S.A.). Gas samples were taken and analysed on the same days when temperature and grain samples were taken. The gas analyser was tested and calibrated against known CO_2 concentrations taken from cylindered CO_2 gas before each sampling date.

Results

Insect infestation

Insect population consisted of *Sitophilus oryzae* (L.), *Rhyzopertha dominica* (F.), *Oryzaephilus surinamensis* (L.) and *Tribolium castaneum* (Herbst). Their total counted numbers served to assess the relationship of their presence in the wheat samples and the associated measured CO_2 concentrations detected at the various depths of the wheat bulk. Although all samples and measurements were taken from 1, 3, 5, 7, and 9 m deep from the grain bulk surface, in Fig. 1 and 2, only the depths of 1, 5 and 9 m were presented. Figure 1 shows that insects were present throughout the observation period from June to mid April. Examination of wheat samples indicated presence of initial infestation in mid-June from average of 0.15 live insects per kg wheat to 2.05 live insects per kg wheat in March. This insect population was greatest at depths of 3 m (not shown in Fig. 1) and 5 m from the grain bulk surface. Examining the insect populations revealed that towards December there was a slight increase in the total population size, then a gradual and significant decrease towards March. The initial insect population was of 1 to 4 live insects/kg of wheat. This population grew up to 25 insects/kg of wheat in October-November. At the end of the observations in mid April the insect population decreased to a range of 1 up to 5 live adults/kg under the influence of aeration during the cold months of the year.

Changes in temperature of the grain bulk and the ambient

Wheat temperature was initially high at about 30ºC. By the operation of aeration system there was a gradual decrease in temperature at all tested depths in accordance with the cooling of ambient air, particularly after October and during the cold months prevailing in Israel (October-March). At depths of 3 (not shown in Fig. 1) and 5 m there was a slight increase of temperature by 1ºC and up to 5.5ºC, respectively. The aeration was performed intermittently to reduce the temperature of the grain bulk from initial 28.3º-34.8ºC in June to 16.5º-20.0ºC in March.

Changes in carbon dioxide concentrations

Carbon dioxide concentrations were measured at all sampled depths and they varied from close to undetectable levels at initial samples to up to 9% when wheat temperature dropped to 20ºC in March. Carbon dioxide concentrations were detected at all tested depths and throughout the observations period from June to mid April. There was a fluctuation in the gas concentrations that increased consistently after each operation of the aeration system. Those concentrations gradually increased with the increase in insect populations. However, the CO_2 concentrations were at their minimal level just before operating the aeration system and increased immediately after the cessation of operating the aeration system and then gradually dropped until the next fan operation. Such increase in CO_2 concentration was observed after each aeration period.

Wheat moisture content

The initial moisture content (wet basis) of the wheat samples at the start of observations in June was in the range of 10.5% to 12.6%, while at the end of the observations in April was of 10.4% to 10.9%. Examination of the samples taken from different depths of the grain bulk showed no increase in moisture content.

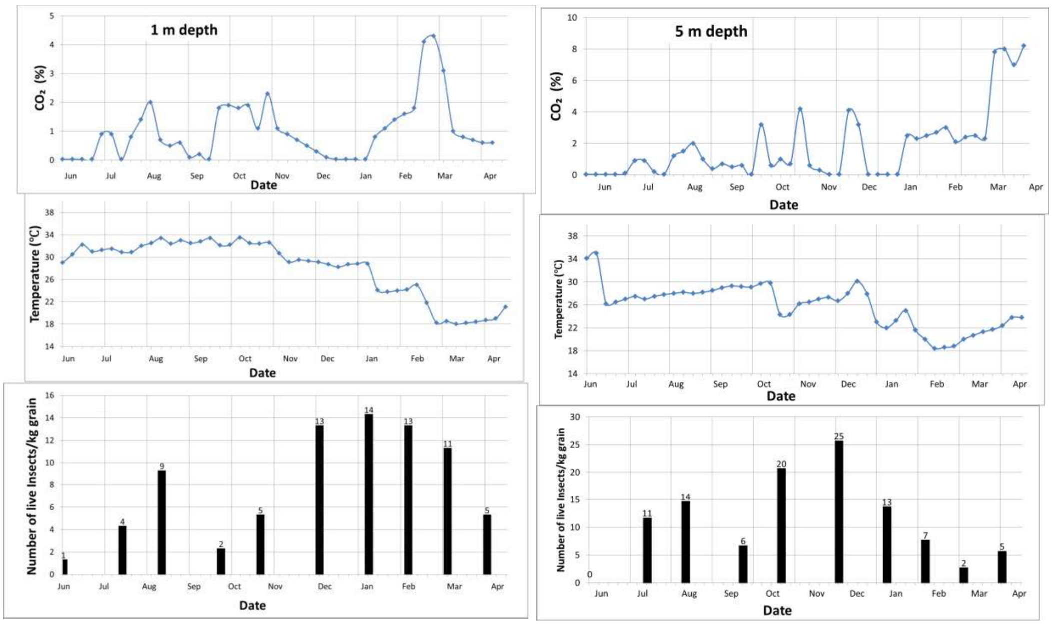

Fig. 1. Monitored CO_2 concentrations, temperatures and number of live insects/kg wheat found in grain samples taken from depths of 1 m (left) and 5 m (right) during 10 months observation of a wheat bulk of 180 tonnes stored in a vertical bin of 14.5 m height.

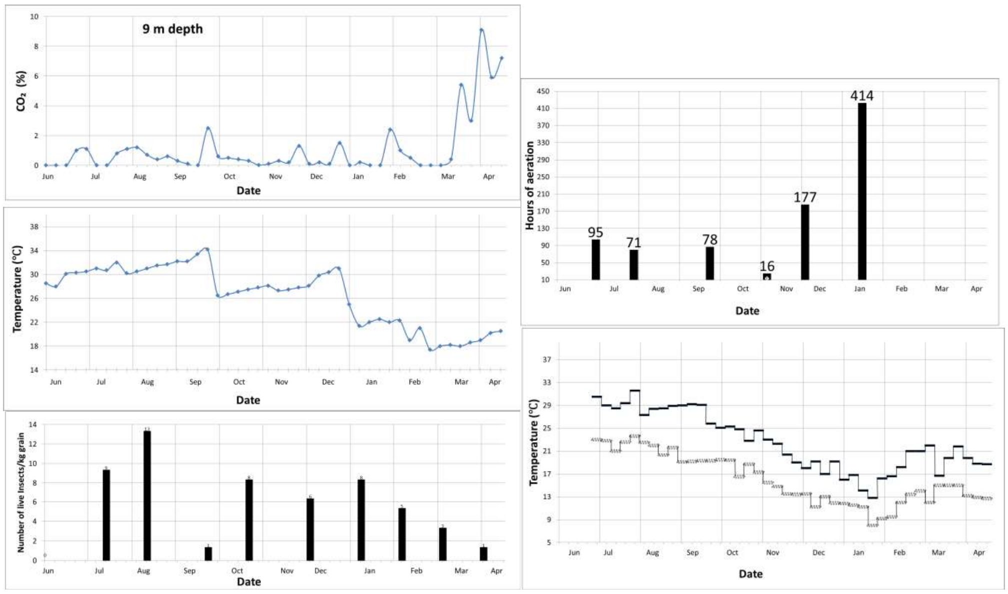

Fig. 2. Monitored CO_2 concentrations, temperatures and number of live insects/kg wheat found in grain samples taken from depth of 9 m (left), number of hours of aeration fan operation, ambient average maximum and minimum weekly temperatures during 10 months of observation of a wheat bulk of 180 tonnes stored in a vertical bin of 14.5 m height.

Discussion

Early works carried out by several researchers have already indicated the advantages of detecting insects by their CO_2 production (Calderon and Shayya, 1961; Howe and Oxley, 1952; Muir et al., 1980; Muir et al., 1985; Neethirajan et al., 2007) and more recently Zhang et al. (2014) has reported on a site-directed CO_2 detection method for monitoring the spoilage of stored grains by insects. Although all those early works led to promising results, the tested CO_2 production by insects, was not disturbed by air currents. Furthermore, some of the works were carried out under laboratory conditions and very little information was made available to correlate the effect of convection currents or the effect of aeration systems in detecting CO_2 concentrations in relation to insect population. Therefore, those works have not considered how quickly the CO_2 produced by insects can be easily detected and correlated when there is air movement inside the grain bulk. In addition, some of those works have considered particularly detecting only the spoilage of grain mainly under the influence of microbial activity developed at moisture contents above their critical level for safe storage (Bartosik et al., 2008; Maier et al., 2006; Maier et al., 2010; Jian et al., 2014) and not due to insect activities.

The present study indicates that the CO_2 produced can be attributed only to insect activity because the tested wheat bulk had a very low moisture content (10.4% to 10.9%). This moisture, in terms of equilibrium relative humidity in air is very close to 53%. That moisture eliminates the possibility of any CO_2 production due to microflora activity.

An interesting unexpected peculiar development was the increase in CO_2 concentration immediately after aeration. When we compare the CO_2 concentrations immediately after aeration, there was always an increase of CO_2 concentration, almost at all tested depths of the grain bulk. In the present study, to condense the report, only three depths were reported (1 m, 5 m and 9 m depth). However, in reality, we tested two more depths (3 m and 7 m depth) that exhibited the same pattern as in the reported depths. Authors have no logical explanation to this remarkable and peculiar development to the increase in CO_2 concentration.

Carbon dioxide concentrations progressively increased with the increase in insect populations. At 5 m depth it was 8% and at the depth of 9 m it was 9%. Although the bin was not sealed and no gas tightness operations were performed, CO_2 concentrations were detectable even after operating the aeration system that practically should have removed all CO_2. Although these results indicate the possibility of detecting insect infestation deep in the grain bulk, at the end of the observations, at 1 m depth CO_2 concentration was only 0.5%. These results indicate the difficulty to correlate the gas concentration to the size of insect population. We postulate because the CO_2 gas is constantly under the influence of convection currents created due to the changing temperature in the grain bulk, mainly in the tested particular case, due to the effect of ambient aeration. This study revealed the potential and the limitations of the application the CO_2 as an indicator to detect insect infestation.

Conclusions

This study revealed the possibility that even in aerated dry wheat bulks, insect presence could be detected by their metabolic activity that generates significantly detectable CO_2 levels as high as 9% in the interstitial air. There was a progressive increase in the size of insect population and the detected CO_2 concentrations. There was also an unexpected peculiar development of CO_2 concentration immediately after each intermittent aeration. It was clear that CO_2 readings were strongly affected, due to the influence of convection currents, that prevented the possibility to correlate with the existing insect populations.

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