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CO_2 MONITORING SYSTEM FOR STORAGE OF GRAINS AND SEEDS

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Keywords:
Arduino
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ABSTRACT

The monitoring of grain and seeds characteristics is fundamental to maintain postharvest quality. Grain mass changes through CO_2 levels monitoring can reduce the product deterioration by anticipating actions to maintain the grain mass quality. This study aimed to develop a CO_2 monitoring system in stored grains/seeds and to analyze its efficiency. The analysis was performed in four crop species (brachiaria, sunflower, corn, and soybean) with different water content and sanity condition. The system hardware was composed of a controller micro board, CO_2 sensor and data stored module. The system routine was developed in C^{++} language. The monitoring of CO_2 and flammable gases was performed for system analysis and verification. The system monitoring developed showed efficiency in CO_2 levels determination in stored grains/seeds and low-cost, being a viable and applicable tool aiming to the maintenance of postharvest quality.

Palavras-chave:
Arduino
Gases
Conservação de grãos
Teor de água

SISTEMA DE MONITORAMENTO DE CO_2 PARA ARMAZENAMENTO DE GRÃOS E SEMENTES

RESUMO

O monitoramento das características dos grãos e sementes é fundamental para manter a qualidade pós-colheita. As alterações da massa de grãos através do monitoramento dos níveis de CO_2 podem reduzir a deterioração do produto, antecipando ações para manter a qualidade da massa de grãos. Este estudo teve como objetivo desenvolver um sistema de monitoramento de CO_2 em grãos/sementes armazenados e analisar sua eficiência. A análise foi realizada em quatro espécies de cultivo (braquiária, girassol, milho e soja) com diferentes teores de água e condições de sanidade. O hardware do sistema foi composto por uma microplaca controladora, sensor de CO_2 e módulo de armazenamento de dados. A rotina do sistema foi desenvolvida em linguagem C^{++}. O monitoramento de CO_2 e gases inflamáveis foi realizado para análise e verificação do sistema. O sistema de monitoramento desenvolvido mostrou eficiência na determinação dos níveis de CO_2 em grãos/sementes armazenados e baixo custo, sendo uma ferramenta viável e aplicável visando a manutenção da qualidade pós-colheita.

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INTRODUCTION

Grains and seeds are biological material, being subject to insects and microorganisms contaminations, which act consuming carbohydrates and lipids causing qualitative and quantitative losses (LISBOA *et al.*, 2017; GOLDEN *et al.*, 2018; SILVA *et al.*, 2021). In Brazil, losses during storage can reach 45.53 % of total post-harvest losses, representing an economic impact of billions of reais (CAIXETA FILHO & PÉRA, 2021). Several storage techniques have been used to slow up the deterioration process, being associated with characteristics such as storage time, product moisture, temperature and relative humidity (ZIEGLER *et al.*, 2021; CAPILHEIRA *et al.*, 2019).

Grains and seeds characteristics can be affected by high temperature and humudity conditions, which deterioration process is increased with metabolic process intensification (PARAGINSKI *et al.*, 2015; ROCHA *et al.*, 2017; JAQUES *et al.*, 2018). The increment of metabolic activity in grains or seeds mass causes an increase in CO_2 production (TAIZ *et al.*, 2017; GOLDEN *et al.*, 2018), which is adopted as an indicator of product changes. The use of low quality grains, due to failures in the post-harvest process, influences the characteristics of the products from this source, with a consequence on its composition and animal health (SULEIMAN *et al*. 2018; WENNECK *et al.*, 2021).

The use of gas sensors in postharvest stages of agricultural products can help to maintain quality, to reduce potential damage and loss of commercial value (DELIBERADOR *et al.*, 2019; CONAB, 2021; RAMACHANDRAN, 2022). In this way, the study aimed to develop and to analyze the efficiency of a low-cost system for monitoring CO_2 in stored grains and seeds.

MATERIAL AND METHODS

The study was developed at State University of Maringá, in Maringá, Brazil, being performed in two stages: in the first stage it was performed the construction and developed the system (hardware and routine), and in the second stage the equipment was used for monitoring grains and seeds stored under different conditions.

System development

The hardware system consisted of a microcontroller board uno (arduino®) model with 14 analog ports and 6 digital ports, with 5V of power supplied to each input/output of the ports, according to Figure 1A. A bivolt source (9 V and 2 A) was used to power the board. The sensors used were MQ135 (Figure 1B) and MQ2 (Figure 1C), usually used for gases and air quality.

The sensor MQ135 allows the detection of benzene, alcohol, carbon monoxide (CO) and carbon dioxide (CO_2) gases in the working range between 100 and 10,000 ppm, while the sensor MQ2 allows the detection of flammable gases (methane, propane, butane, hydrogen, alcohol, natural gas) in the range between 300 and 10,000

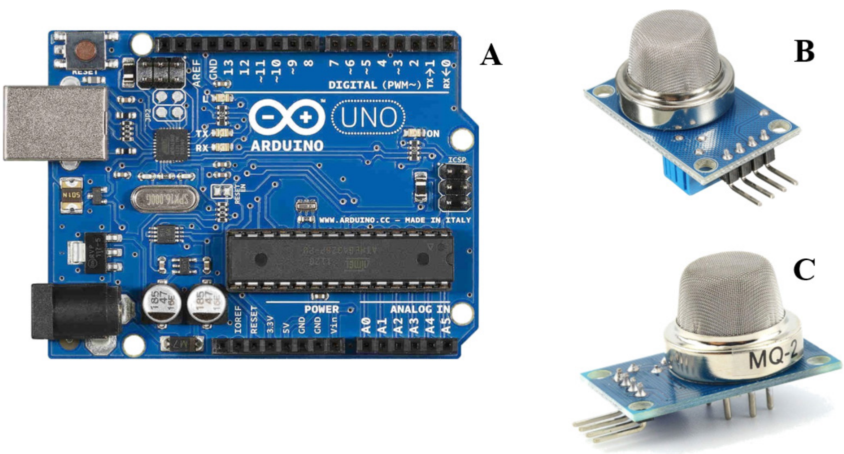

Figure 1. System components. A) Microcontroller board Arduino Uno model; B) Sensor MQ135; C) Sensor MQ2

ppm. A sensor is included in the system considering the explosion risk that improperly managed grains storage systems can present.

For CO_2 detection using only the MQ135 sensor, calibration and adjustment of the characteristic curve for the gas according to the sensor manual (WAVESHARE, 2021) was performed. The source code upload for the microcontroller board was performed through USB connection.

Arduino (IDE)™ software version 1.8.13, using the C^{++} language, was used for routine system code development . In source code development SD, SPI, MQ135 and MQ2 libraries were used (ARDUINO, 2021). The sensors were connected to digital ports, and data collect was performed at scheduled intervals. Data were stored in a micro-SD card in text file format (txt). For data extraction, Microsoft Excel™ software was used. The equipment allows continuous readings, with programmable intervals, whose operational capacity is related to the energy supply and storage capacity of the memory card used.

During the evaluations, temperature and relative humidity data were obtained with commercial equipment (GSP-6 datalogger, Elitech™). However, the availability of analog ports on the controller chip allows the inclusion of temperature and relative humidity sensors, as long as they are included in the source code and properly calibrated.

The moisture content in the grains and seeds was determined by the gravimetric method. Samples were kept in an oven with forced air circulation at 105°C for 24 hours. The difference in mass was performed and the result was expressed in percentage dry basis (% db).

The development of the equipment was evaluated by monitoring some gases (CO_2 and flammable) in grains and seeds of brachiaria, sunflower, corn and soybean in different conditions.

Microenvironment of seeds and grains evaluated

Sunflower and brachiaria seeds, with moisture contents ranging from 5% to 25% db were placed in glass containers (1 dm^{-3}) to determine CO_2 concentration. The sensor MQ135 was positioned 10 cm above the seed surface and data collect was performed each 30 s for 15 min. During evaluation, the glass container was kept closed. Data from 5 minutes from the beginning of the evaluation were disregarded, considering the period for stability of material and CO_2 levels. During evaluation, CO_2 levels in the environment air were monitored, expressed by CO_2 increment in relation to the environment in function of seed moisture.

Soybean grains with moisture content ranging from 7% to 24% were stored in glass Becker, for immediate reading of CO_2 levels with sensors positioned on the grain surface. Ten readings of gases (CO_2 and flammable) concentration were obtained with an interval of 10 s.

In the container prototype (0.5 m diameter and 0.6 m high) built with metal plates, soybean grains had water content of 8±2%. The prototype was filled with 90% of its capacity and kept in an environment with non-controlled temperature and relative humidity conditions. The temperature and relative humidity were monitored during the storage using sensors coupled to a GSP-6 datalogger (Elitech™). CO_2 (MQ135) and flammable (MQ2) sensors were installed 0.15 m from the surface of the grain mass. The data collection (CO_2, flammable gases, temperature and relative humidity) was performed with intervals of 1 hour being monitored for 70 hours.

Corn seeds with moisture between 7% and 17% were stored in terephthalate polyethylene packaging for 45 days, in uncontrolled temperature and relative humidity conditions. After storage, material samples were placed in glass Becker for immediate CO_2 reading with sensors positioned on the seed surface. Ten gases concentrations (CO_2 and flammable) were performed with intervals of 10 seconds.

Two sanitary condition of corn grains (healthy and infested with *Sitophilus zeamais*), from rural property storage were placed in glasses package (1 dm^{-3}) for CO_2 concentration determination. The MQ135 sensor was positioned 10 cm of the seed surface mass and CO_2 levels were monitored for 40 hours. During evaluation, the package was kept closed to avoid gas exchange with the environment.

Additionally, a test was performed to evaluate the effect of *S. zeamais* infestation on the CO_2 emission in hermetic environment. Intact corn grains with water content of 12±2% db were stored in glass package (500 mL). The infestation was performed with 10 adults insects (*S. zeamais*) without gender ratio control (males and females). The sensor (QM135) was inserted above the grain surface, being the CO_2 levels monitored in intervals of one minute for 40 hours.

The conditions of the material and the objective of the test were considered to define the range of readings and duration of the analysis. In the evaluations with stable conditions (constant water content and material integrity), concentration readings were performed in short periods (10 s to 1 min). For monitoring analysis over long periods (40 and 100 hours), in which there was no constant storage condition, the interval between readings was set at 1 hour, considering the amount of data obtained during the analyzed period.

Statistical analysis

The CO_2 and flammable gases levels obtained in the different conditions of the experiment were submitted to regression analysis. Microsoft Excel™ and SISVAR (FERREIRA, 2019) software were used to the data analysis.

RESULTS AND DISCUSSION

The developed system allowed verifying that the variation in the water content of sunflower and brachiaria caused a significant increase in CO_2 levels (Figure 2). Flammable gas data is not presented, as there are no significant differences in the evaluated conditions.

The use of MQ135 sensor is possible due to stability in CO_2 level readings, with low standard deviation between the values and high sensitivity to variations in the storage condition. The data is important, as it allows low variation of the readings in the range of water content in the product from 1 to 2% db.

Considering the monitoring technique, MQ2 sensor when properly calibrated can also be used for CO_2 determination. However, in the studies performed by Wang *et al*. (2010), its utilization showed low sensibility on detection, justified by the reaction between surface oxygen and water molecules that cause a decrease in the sensor's basal resistance.

A similar trend for the sunflower and brachiaria seeds was obtained with soybean grains in function of the increase of water content (8 to 33 % db). The CO_2 levels in the stored grain mass increased according to the product's water content (Figure 3). According to Suleiman *et al*. (2018), CO_2 levels in stored grains are related to the condition of water content in the grains and storage time, also influencing insect infestation and aflatoxin production.

The maximum standard deviation obtained in CO_2 and flammable gases readings was 1.90 ppm. Stored grains with high moisture showed visually deteriorated, with reflection on the CO_2 and flammable gases levels in the grain mass (Figure 3). This observation has shown that the

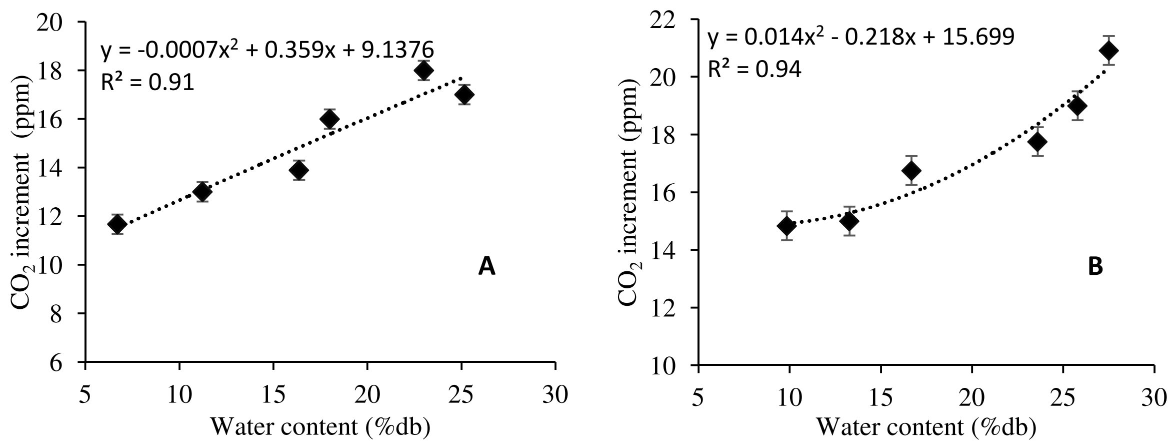

Figure 2. Increment of CO_2 concentration in seeds stored with different water content in relation to the environment levels to sunflower (A) and brachiaria (B) seeds

CO_2 determination levels through the sensors was able to identify focus of deterioration in the grain mass. Therefore, the use of this tool allows an strategic control to minimize the resulting damages (DELIBERADOR *et al*., 2019; CONAB, 2021).

According to Ziegler *et al*. (2016) the soybeans grain quality cannot be improved during postharvest. They can be only preserved, being necessary careful control mainly in relation to air humidity in order to avoid compromising the integrity and nutritional value of the grain. Thus, the development of mycotoxins as result of inadequate storage conditions compromises the sanity of soybean by product.

Although CO_2 levels alterations directly show relation with factors that promote deterioration of the stored material, variation could be related to the storage environment conditions, considering the grain mass has dynamic exchanges with the environment, and the storage is performed mainly under uncontrolled conditions (HUANG *et al.*, 2013; SILVA *et al*., 2021). The temperature during storage was above 25.5ºC and the relative humidity above 66% (Figure 4) using GSP-6 datalogger.

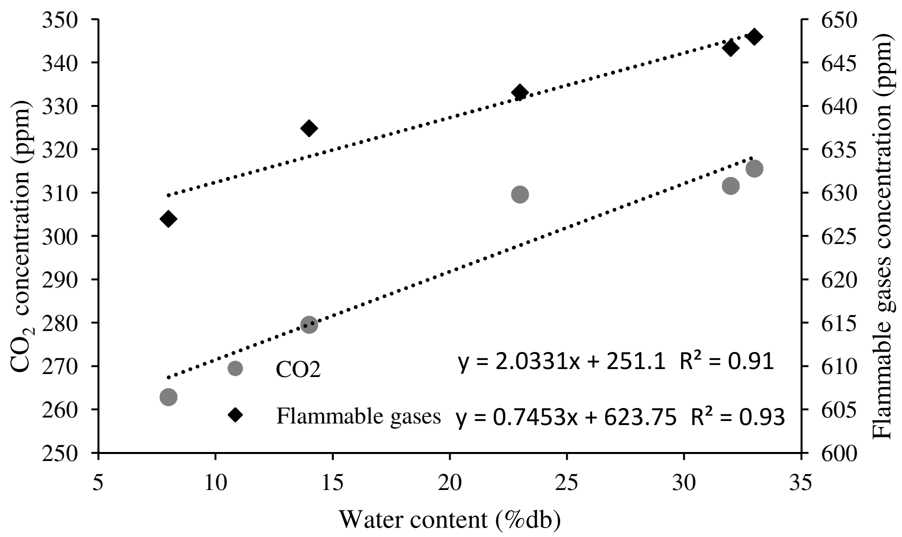

Figure 3. CO_2 and flammable gases concentration in soybean stored grains with different water content

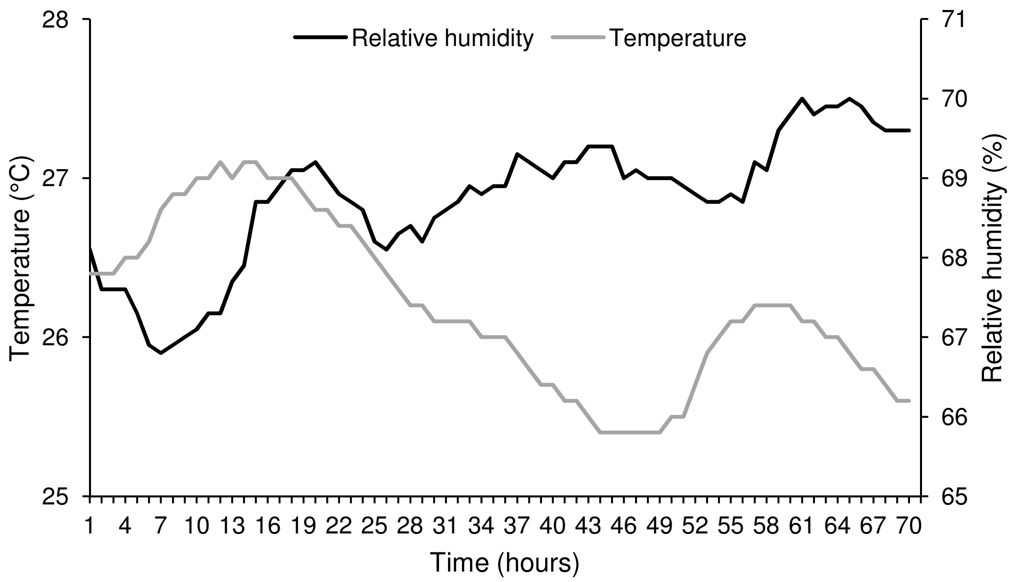

Figure 4. Temperature and relative humidity of the ambient air inside the silo during soybean storage

The CO_2 concentration showed a minimum value of 179 ppm and a maximum of 223 ppm, while the concentration of flammable gases ranged between 421 and 534 ppm (Figure 5), using the proposed system.

The environment air conditions present directly relation under the grain equilibrium moisture, resulting in alterations in water activity and biochemical reactions in grains, which consequently influences the presence and activity of insects and microorganisms (GOLDEN *et al*., 2018; ZIEGLER *et al*., 2021).

The results obtained in the study allow creating a database to determine tolerable intervals in the variation of CO_2 and flammable gases levels without changes in product quality and integrity.

Similar trend to soybeans grains (Figure 3) was observed when determining gases concentrations (CO_2 and flammable) in corn seeds stored with different water contents (7, 11, 14 e 17% db) after 45 days of storage (Figure 6).

The increase of CO_2 levels occurs due to the increase of product respiration. As consequence of biochemical processes, there is consumption of product energy reserves able to affect the germination potential and vigor in seeds (ZIEGLER *et al*., 2016; LISBOA *et al*., 2017; GOLDEN *et al*., 2018; SILVA *et al*., 2021). In the grain mass, infestations and hot spots cause an increase in the production of CO_2, which moves in the intragranular spaces and can be detected by sensors (RAMACHANDRAN, 2022).

High CO_2 levels can also be related to technical break of grains caused by insect attack (NEVES & SAVELLI, 2017), as observed in corn grains stored with different sanitary conditions. The grain lot infested with *S. zeamais* showed higher CO_2 levels in relation to the lot without insects presence (intact grains) (Figure 7). According to Golden *et al*. (2018) the insect's presence provides elevation of CO_2 concentration in the storage.

In the monitoring of grains mass, a concentration of CO_2 above 270 ppm was observed in the infested lot, while in the intact lot (without insect infestation) the concentration was below 250 ppm (Figure 7). Thus, the readings obtained in the monitoring system allowed the lot differentiation regarding sanitary conditions.

Considering the constancy of CO_2 values obtained in corn lot with intact grains (Figure 7), the monitoring of CO_2 levels was performed after infestation of *S. zeamais* in intact corn grains.

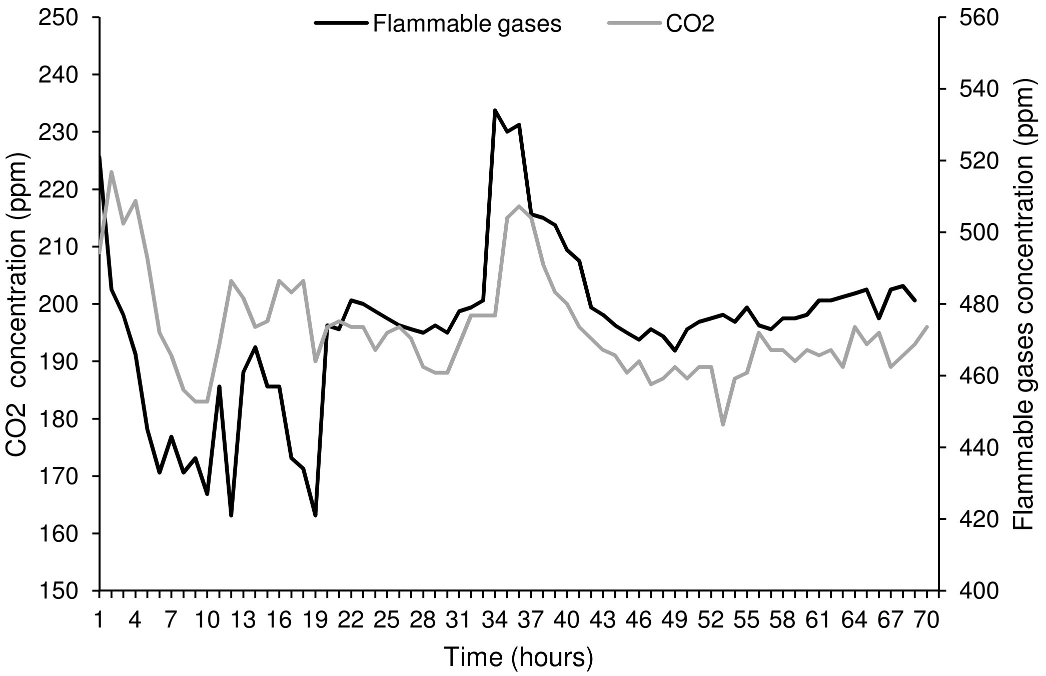

Figure 5. Gases concentration during soybean grains storage in prototype silo

During the monitoring there was an coniderable increase in CO_2 concentration, ranging from 262 ppm (start) to values above 270 ppm after 30 minutes, and higher than 285 ppm after two hours of storage (Figure 8), with increase associated with insect activity in grain mass.

After 20 hours of storage there was reduction of CO_2 levels (Figure 8). This result is probably associated with conditions of temperature, relative humidity, light and oxygen levels on the action of insects, which are uncontrolled factors in the experiment.

At the end of the storage time there was not presence of live insects, whose death is associated with the absence of gas exchanges between the environment and package, as reported by Golden *et al*. (2018). The increment of CO_2 levels can cause mortality of insects, being adopted as management strategy of control (SULEIMAN *et al*. 2018; DIAS *et al*., 2020).

The market offers different sensor options for determining CO_2 concentration, including even

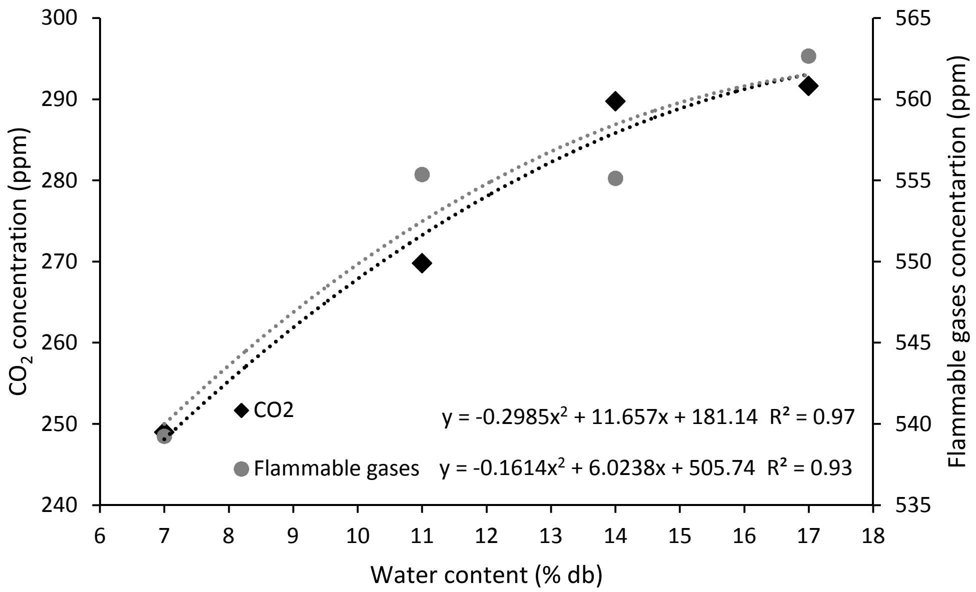

Figure 6. Concentration of CO_2 and flammable gases in corn seeds stored after 45 days with different water content

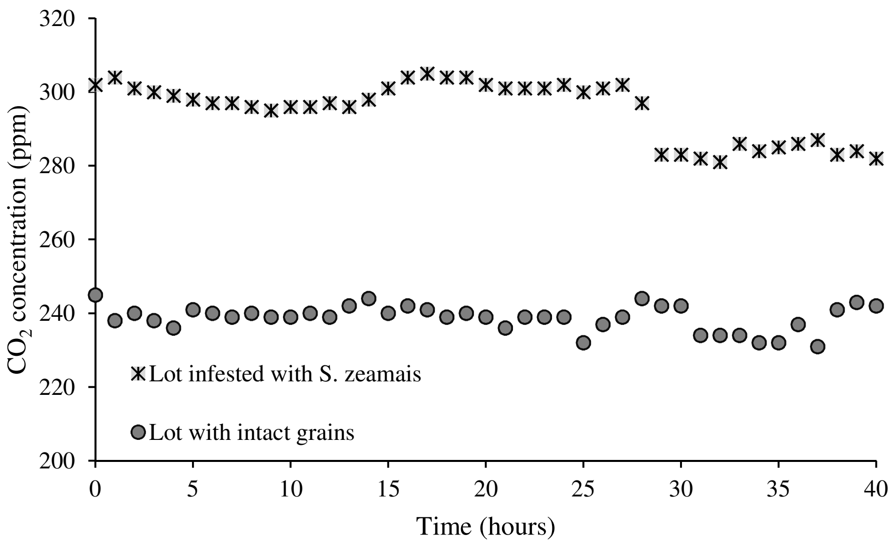

Figure 7. Monitoring of CO_2 concentration in corn grains with different sanitary conditions

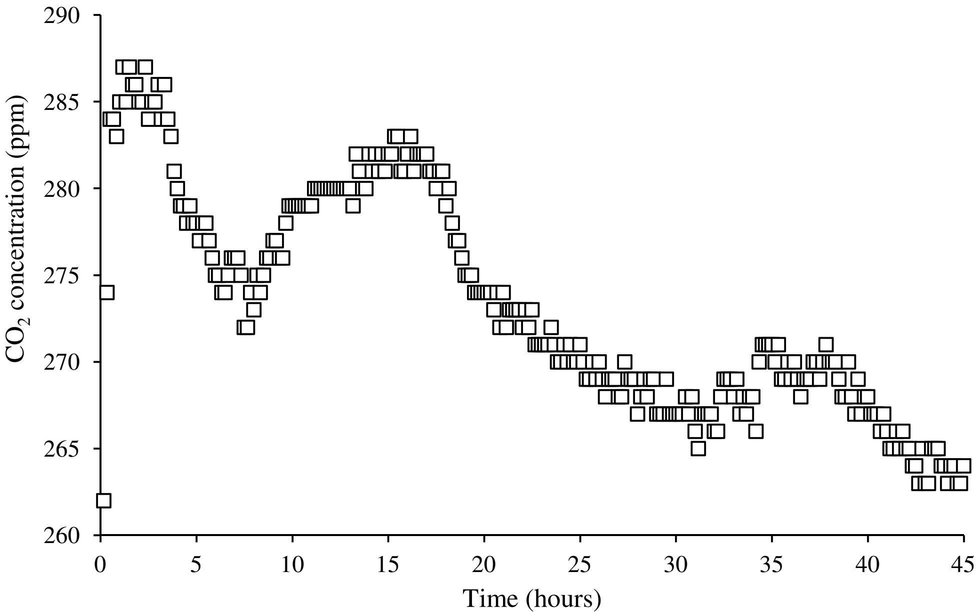

Figure 8. Values of CO_2 concentration in stored corn grains after infestation with *S. zeamais*

MQ2 sensor if properly calibrated. According Wang *et al.* (2010), although its calibration was carefully checked, the MQ2 sensor did not show sensitivity to variation of CO_2 concentration in stored grains.

The MQ135 sensor used in this study to determine CO_2, had a unit cost of US$ 5. In the present study, the developed monitoring system with all the components presented cost less than US$ 100. However, to define the economic viability of the system, future studies are needed comparing the proposed system to the equipment available in the market.

CONCLUSION

- The monitoring system showed efficiency in the determination of CO_2 levels in grains/seeds in different species.
- Considering the sensor sensibility regarding the grain conditions (water content and grain sanity) and the different agronomic species evaluated, the system show technical viability for monitoring stored grains. In addition, the operationalization of carbon dioxide monitoring (CO_2) system can contribute as a tool to maintain the stored grains quality throughout the year.

AUTHORSHIP CONTRIBUTION STATEMENT

WENNECK, G.S.: Conceptualization, Investigation, Software, Writing – original draft; **SAATH, R.:** Conceptualization, Project administration, Supervision, Writing – review & editing; **WENNECK, G.S.:** Data curation, Formal Analysis, Investigation, Validation; **PEREIRA, G.L.:** Formal Analysis, Writing – review & editing; **VILA, V.V.:** Writing – original draft; **ALVES, L.H.B.:** Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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