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Temporal valuation of corn respiration rates using pressure sensors

Gagandeep Singh Ubhi, Sammy Sadaka*

Biological and Agricultural Engineering Department, University of Arkansas, Division of Agriculture, Arkansas, USA

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ABSTRACT

Proper grain management requires chronological and precise measurements of carbon dioxide evolved from grain respiration during the postharvest storage duration. The main goal of this research was to develop a new technique that evaluates temporal corn respiration rate using pressure sensors. The effects of corn storage temperature (23, 35, and 45 °C) and initial moisture content (12.9, 14.8, 17.0, 18.8, and 20.7% w.b) on the cumulative respiration were studied for duration of nine days. Additionally, the established technique was used to develop an empirical equation to predict the corn respiration rate as affected by storage temperature, moisture content, and storage duration. The pressure sensor method was found to be reliable in measuring corn respiration rate as affected by the tested parameters. The highest cumulative respiration of 2.625 g/kg was observed with the moisture content of 18.8% and the medium temperature level of 35 °C after nine days. Increasing and/or decreasing the moisture content level from 18.8% negatively affected the cumulative respiration. Respiration rates reached their maximum values of 0.199, 0.755, 0.987, and 1.147 g/kg.d under the medium temperature level of 35 °C and the moisture contents of 14.8% (5th day), 17.0% (5th day), 18.8% (3rd day), and 20.9% (2nd day), respectively. The logarithmic value of the corn cumulative respiration was positively correlated with the initial moisture content values, the storage temperature, and the storage duration with an adjusted coefficient of determination value of 0.80.

1. Introduction

Synthesis of proper grain storage strategies is the key to retaining them active for a longer period without suffering any losses such as weight loss, quality loss, health risk, and economic loss (Chow, 1980). The proper storage procedures and management practices are desirable to follow as reported by Chidananda et al. (2014). One of the indications related to crop activity, during their storage that could be measured independently is grain respiration. It is a parameter of interest to study because it affects the storage life of the commodity. Respiration is a metabolic process where oxidative breakdown of complex molecules such as sugars or carbohydrates takes place. It results in the evolvement of carbon dioxide and water accompanied by generation of heat (Forcier et al., 1987). Liu et al. (2011) stated that respiration has a significant influence on crop yield because dry matter accumulation is strictly related to adjustment of CO_2 and respiratory activity. The respiration of a corn mass under aerobic conditions has been modeled as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2835kJ/gram\ mole \quad (1)$$

This equation relates the amount of CO_2 evolved to the dry matter loss, where 14.6 g CO_2 evolved per kg of original dry matter corresponds to 1% dry matter loss (Steele and Bern, 2002).

The rate of grain respiration is influenced by internal as well as external factors. The type and maturity of the grain are the internal factors affecting its respiration rate. Respiration rate typically declines as the crop matures; commodity harvested at active growth stage respires faster than the one harvested after attaining complete maturity (Saltveit, 2004). On the other hand, moisture content and temperature as well as oxygen and carbon dioxide concentrations are the major external factors affecting grain respiration rate. Fonseca et al. (2002) and Gonzales et al. (2009) reported that moisture content and temperature of stored grain are the main factors affecting their deterioration. Accordingly, these factors might be monitored and controlled to maintain grain quality and to quantify any mold growth and insect infestation.

Oxygen and carbon dioxide concentrations, in storage tanks, also influence grain respiration rate. Decreased availability of O_2 slows down the respiration activity due to reduced metabolic activity. Similarly high CO_2 concentration in the atmospheres

* Corresponding author.
E-mail address: ssadaka@uaex.edu (S. Sadaka).

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surrounding the grain, reduce the respiration metabolism as reported by Herner (1987). High carbon dioxide concentration had been proved as a biological activity responsible for spoilage of stored wheat (White et al., 1982).

Karunakaran et al. (2001) reported that deterioration rates were determined by measuring germination capacity of grain and respiration rates of grain and microorganisms. Maier et al. (2010) found that insects, fungi, and grain metabolism cause the elevated CO_2 levels in storage tanks. Accordingly, monitoring CO_2 levels help detecting spoilage early.

Brecht (2004) reported that sweetcorn respiration rate increased from 30 to 51 mg CO_2 kg^{-1} h^{-1} at 0 °C to 282–435 mg CO_2 kg^{-1} h^{-1} at 25 °C. Chidananda et al. (2014) measured respiration rate as affected by moisture contents and temperatures for pinto bean, chickpea, and green lentil stored for one month. They found that respiration rates increased with increase in moisture content and temperature. Additionally, Srour (1988) found that grain respiration increased in an exponential manner with increase in temperature and moisture content. Bunce (2004) showed that the low temperature reduced rates of respiration while high temperature increased rates of respiration. Karunakaran et al. (2001) mentioned that respiration rates of 17–19% moisture content wheat at 25 °C were higher than the 15 and 16% moisture content wheat stored at the same temperature. High moisture accompanied by high temperature provides the optimum conditions for fungi to grow (Chow, 1980).

Respiration rate of biological material is closely tied to its metabolic activity, which is influenced by both biotic and abiotic factors. As a result, microbial and grain respiration contribute to the total respiration in the system (Christensen, 1955). High respiration rate under high moisture provides a suitable environment for *Aspergillus flavors* to flourish and produce aflatoxins. Aflatoxins have been regarded by IARC (International Agency for Research on Cancer) as toxicity class I chemicals and carcinogenic in nature (Piotrowska et al., 2013). Chitrakar et al. (2006) reported that carbon dioxide generation during aerobic respiration is a useful measure of the microbes activities that decompose organic materials. Hence, it is essential to measure the CO_2 concentration dynamically to monitor the respiration rate of the grains.

Grain respiration measurements had been typically quantified directly or indirectly. Physical and chemical measurements are the base for the direct methods, in which physical methods have been considered as more efficient. Direct methods usually measure the concentration of carbon dioxide (CO_2) produced directly from the grain. On the other hand, indirect methods measure some properties associated with the crop, such as pressure or volume changes within a closed bottle, which is correlated with the concentration of CO_2 and O_2 liberated and consumed, respectively.

Various techniques had been developed during the last few decades to quantify grain respiration. The commonly used methods to measure CO_2 production are divided into static and dynamic system measurements. In the static systems, the produce is placed in some airtight containers and the measurements are done either by drawing gas samples continuously or by monitoring gas concentration with some sensing device. Alternatively, in a dynamic system, the difference in CO_2 concentration between the exit and inlet air represent the respiration during this period (Saltveit, 2004).

Chitrakar et al. (2006) used a test kit to measure CO_2 generated during respiration of organic materials. The Solvita® Corn Testing Procedure, used by them, was shown to be capable of quantifying the storage state of corn over a range of moistures and durations of incubation after re-wetting. Computer controlled automatic respirometer, using manometry as a fundamental principle, was designed to access the respiration of biological materials (Janni et al., 1981). In another experiment, an electronic sensor was devised, and its credibility was established by comparing its results with gas chromatography results (Forcier et al., 1987). Chidananda et al. (2014) also, used the gas chromatographic technique to measure the respiration rate of pulses under different environmental conditions. Hamer et al. (1991) fabricated an automatic electrolytic respirometer, which measured the current flowing through the electrolytic solution, and obtained the volume of O_2 consumed in the process. In addition, a resistance-based sensor has been developed to detect the spoilage in stored grains, employing polyaniline boronic acid polymer as sensing element (Neethirajan et al., 2009). In an earlier study, Sadaka et al. (2006) used automated pressure sensors to measure respiration of organic materials. This method used the pressure drop due to O_2 consumption in the container for calculating respiration rate. The CO_2 produced was trapped with sodium hydroxide (NaOH) pellets to eliminate its effect on the pressure. The readings were compared with time-tested titration method and found to be in a high degree of agreement ($R^2 = 0.92$).

Most of the research has been attentive on measuring the respiration intermittently. Grain respiration activity in the storage bins may change suddenly. Accordingly, intermittent respiration measurements may not allow tracking the changes in the respiratory behavior of the crop. These intermittent respiration measurements could lead to inappropriate decision making, and the recorded data might not be entirely representative. The major issue facing grain-handling management is that the hotspots may occur far away from temperature sensors in bins, silos, and tanks making early detection of spoilage difficult. Consequently, there is a rising demand for continuous sensing of carbon dioxide (CO_2) during grain storage. This is because CO_2 sensors can be used to detect spoilage and to assess CO_2 levels in modified atmosphere storage structures as reported by Neethirajan et al. (2009). The market perspective for reliable and inexpensive CO_2 sensors is enormous because of a broad range of applications in the agri-food industry. Therefore, there is a need to develop a technique for continuous monitoring of respiration. Hence, the goal of this study was to establish an innovative method to evaluate corn respiration rate on temperoal basis. The specific objectives were to: (a) study the effects of temperature, moisture content, and storage duration on grain respiration rate; and (b) quantify the corn cumulative respiration as a function of storage temperature, moisture content, and storage duration.

2. Materials and methods

2.1. Corn collection and preparation

Dry corn (*Zea Mays* L.) was procured from a local farmer and stored at 4 °C. This corn was harvested about nine months earlier. The initial moisture content of corn was determined using the standard method (ASABE, 2008). About 10 kg corn sample was visually selected to avoid any damaged corn kernels. The sample was divided into five subsamples and stored in polyethylene bags. The targeted moisture content levels were 13, 15, 17, 19, and 21% w.b. The required amount of distilled water was added to the corn in the polyethylene bag with the help of spray bottles. Corn rewetting technique was found to be an acceptable method of storing the corn for further use in storage studies. Fernandez et al. (1985) reported that no significant difference in CO_2 concentration was observed between the dried-rewetted corn and the samples stored under refrigeration at same moisture level. Following, the samples in the zip lock bags were mixed vigorously to ensure uniform distribution of the added moisture. These five subsamples were again stored in the refrigerator at 4 °C. Thereafter, three