Low Budget Respirometer Chamber Design Based on Wireless Sensor Network

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ABSTRACT

Fresh fruit respiration information is essential optimizing food storage systems. Meanwhile, respiration is defined as the process of oxygen production and carbon dioxide release during storage in a closed respiratory chamber. Therefore, this study aims to design a low-budget computerized respiratory chamber for enhancing fruit packaging and storage system. Real-time fruit respiration can be measured by applying wireless gas sensors network. The respirometer consisted of 3,600 mL glass jar with a screw stainless lid, while the electrochemical and non-dispersive infrared sensors were mounted on the cover of the glass jar for collecting data on the oxygen, carbon dioxide, and temperature during mangoes' respiration. Arduino USB port was used to record all measured parameters consisting of oxygen (%) and carbon dioxide concentrations (ppm, as well as temperature in the respiration chamber. Additionally, a controlled cooling chamber was applied to maintain the temperature during storage, while data communication was supported by Xbee S2C based on radio frequency. According to the respirometer real-time reading, there was a decrease in oxygen concentration caused by increasing carbon dioxide release with temperature. The low-budget respirometer was used to measure the respiration rate and record the data through a wireless sensor network system. The data plot shows that the respiration rate increased as the storage temperature and the respiratory quotient ranged from 0.32-0.44.

Keywords: Fruit; real-time; respirometer chamber; storage; wireless sensor network

INTRODUCTION

Respiration activities influence the metabolism process and shelf life of horticultural commodities. Fruit respiration is one of the main parameters that occur both in the maturation and ripening processes, hence, fresh fruit and vegetables continue to respire after harvest as indicated by the consumption of oxygen and production of carbon dioxide (Belay *et al.*, 2016). These parts are also unique horticultural commodities because they show active physiological processes such as respiration and transpiration that promote ripening or senescence under normal storage conditions (Caleb *et al.*, 2013; Tanner, 2016).

The respiration pattern of the fruit is likely sophisticated during both packaging and storage because several factors potentially accelerate the activities. This includes both internal and external factors such as maturity stage, oxygen and carbon dioxide supply, ethyleneas well as temperature (Fonseca *et al.*, 2002). Determination of respiration rate is time-consuming and involves specific methods or instruments for gas production analysis (Bhande *et al.*, 2008). Consequently, knowledge about respiratory parameters will support

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the development of post-harvest technology for fruits and product packaging as well as storage (Helena Gomes *et al*., 2010).

Understanding the respiration rate can help in controlling the maturation phase to ensure quality fruit and vegetables after harvesting (Barbosa *et al*., 2011). The storage chamber design must be supported by real-time respiration conditions that can analyze parameters such as oxygen consumption and carbon dioxide production. It requires some equipment such as a permeable vessel, responsive sensors for reading and collecting data, as well as insulated cooling storage. The gas sensors are easily supplied and the software can be independently developed to build the prototype design. Hence, the fruit and vegetable respiration can be measured directly as both oxygen and carbon dioxide concentration changes.

An economical and computerized respiratory chamber design is an important device to enhance post-harvest fresh fruit and vegetable storage. Recently, wireless and networks sensors have been introduced for supporting agriculture works such as measuring, monitoring, and control, but their development is just in the early phase (Wang *et al*., 2006). Therefore, the wireless sensor network (WSN) was examined for measuring and monitoring oxygen respiration rate in plants (Lokke *et al*., 2011), storage condition (Green *et al*., 2009)it is possible to detect any significant increases in temperature occurring during silage decomposition. The objectives of this study were: (1, as well as agriculture biomass quality (Bochtis *et al*. 2011)potential changes in specific physicochemical properties must be identified to subsequently act as indicators of silage decomposition and form the basis for preventive measures. This study presents a framework for a diagnostic system capable of detecting potential changes in specific physicochemical properties, i.e., temperature and the oxygen content, during the biomass storage process. The diagnostic system comprises a monitoring tool based on a wireless sensors network and a prediction tool based on a validated computation fluid dynamics model. It is shown that the system can provide the manager (end-user. It can be used to determine respiratory parameters in the post-harvest technology area, such as oxygen consumption. Furthermore, WSN applicable for respiration measurements in temperature or time-dependent experiments. A previous study also stated that wireless systems can be applied to produce measurements without any disturbance (Lokke e*t al*., 2011).

Electrochemical sensors are commonly used for monitoring several gases such as oxygen and carbon dioxide in the agricultural storage MAP system (Fonseca *et al*., 2002). Oxygen detection in the industrial application based on anode metal consumption have been technically and commercially successful (Willett 2014). However, the sensor lifetime limits long duration application although some have a warranty time of approximately 3 years. The use of oxygen and carbon dioxide sensors for fruit respiration investigation must be supported with a microcontroller interface or programmable logic control.

A modular device namely respirometer was developed based on open source software to determine the respiration rates of agricultural produce in a closed system design. Carbon dioxide production was continuously readopted using a non-dispersive infrared sensor while oxygen consumption rate was predicted with barometric pressure (González-buesa and Salvador, 2019). Furthermore, the arduino based electronic control provides an open-source platform as well as compatible software and hardware leading to economical and practical application for biotechnology (Mathupala *et al*., 2016) and egg freshness during storage (Coronel-Reyes *et al*., 2018)consumers are more concerned about freshness and quality of food. Poultry egg storage time is a freshness and quality indicator in industrial and consumer applications, even though egg marking is not always required outside the European Union. Other authors have already published works using expensive laboratory equipment in order to determine the storage time and freshness of eggs. This paper presents a novel alternative method based on low-cost devices for the rapid and non-destructive prediction of egg storage time at room temperature (23 ± 1 °C.

A low-budget respiratory chamber is important for developing an economical device to enhance fruit respiration during storage. The product can be used to encourage fruit handling problems as well as to observe the respiration trend. Therefore, this study aims to design a low-budget laboratory respiratory chamber for fruit storage based on arduino wireless network. The storage chamber was built using sensors that allow the monitoring of the oxygen and carbon dioxide concentration regularly in a fully closed system.

MATERIALS AND METHODS

Materials

This study used two materials namely Harumanis mangoes (*Mangifera indica* L.) and respiratory chamber equipment. The mangoes used were at the matured level or ready to be consumed. They were collected from a local market at Lombok and sorted based on the weight of 450 ± 10 g. Meanwhile, the equipment used include a cooling chamber, sensors, data logger, microcontroller, communication serial, and respiratory chamber.

Cooling chamber

The controlled temperature was prepared by modifying a commercial cooler box made in Polytron SCN 140 with a volume capacity of 165 L and electricity power of 180 W. This cooling chamber was also supported by 70 g refrigerant mass type R 134A while the temperature control indicator was modified using Omron thermostat type E5CWL made in China. Furthermore, the K21 type thermocouple sensor was connected for reading the actual temperature in the. chamber. A switch relay system was also applied which allowed the set-up temperature between 4-30 °C. Relay was connected to the main power by on-off mechanism. The relay position switch was turned on and off when the inner temperature is below and above the set-up point temperature respectively.

Sensors

The Electrochemical K-25F3 model oxygen sensor was obtained from Figaro, Japan. It has a good performance to measure oxygen level and do not influence the carbon dioxide during data measurement. The oxygen sensor has an output voltage from 10-15.5 mV and temperature operation between 5-40 °C. The measurement range was 0 to 100% vol, response time 15 s, and the accuracy was 1% volume while the oxygen concentration and voltage have a linear relationship.

The non-dispersive infra-red MH-Z19 carbon dioxide sensor was supplied from Winsen, China. It has an output voltage ranging from 2.9-5.5 V and supported with a $Li\text{-}SOCL_2$ battery, UART/PWM output signal format, response time less than 60 s, operating temperature between 0-50 °C and can read carbon dioxide concentration from 0-5,000 ppm. Subsequently, the DHT11 temperature and humidity sensor was supplied from Digiware, Indonesia. It can directly read both humidity and temperature at 20-95% and 0 °C-50 °C, respectively using arduino or microcontroller. The temperature and humidity sensors were connected to a 8-bit microcontroller and digital interface.

Microcontroller

The Onboard SD card arduino interface was obtained from LDO power chip onboard AMS1117-3.3 (SRL, Strambino, Italy). This board is based on ATMEGA 328P chip microcontroller (Atmel Corp, San Jose, CA, USA) consisting of 14 digital input/output pins where 6 provide PWM output and 6 for analog input. Arduino UNO has a USB which acts as a communication port for data transfer with the computer. Moreover, Real Time Clock (RTC) module DS3231 chip with embedded battery CR 2032 was used as the power source. The RTC was connected with Arduino through 12C protocol.

Data logger and Communication

Arduino USB port recorded all parameter measurements consisting of oxygen and carbon dioxide concentrations (ppm), as well as temperature and humidity taken every 5 seconds in the respiration chamber. Subsequently, Xbee transmitter and receiver were synchronized to transfer data into the laptop (Sony Vaio, SVT13136CYS, Japan) using software developed by Lab View 2018 National Instrument, USA.

Radio frequency (RF) based on Xbee S2C was applied to support wireless communication and data transfer from the sensors. This module provides 16 direct sequence channels and networks supported topologies including point-to-point, point-to-multipoint, peer-to-peer and digi mesh. The transmission band ranged from 2.4 GHz to 2.5 GHz and RF data speed was up to 250,000 bps.

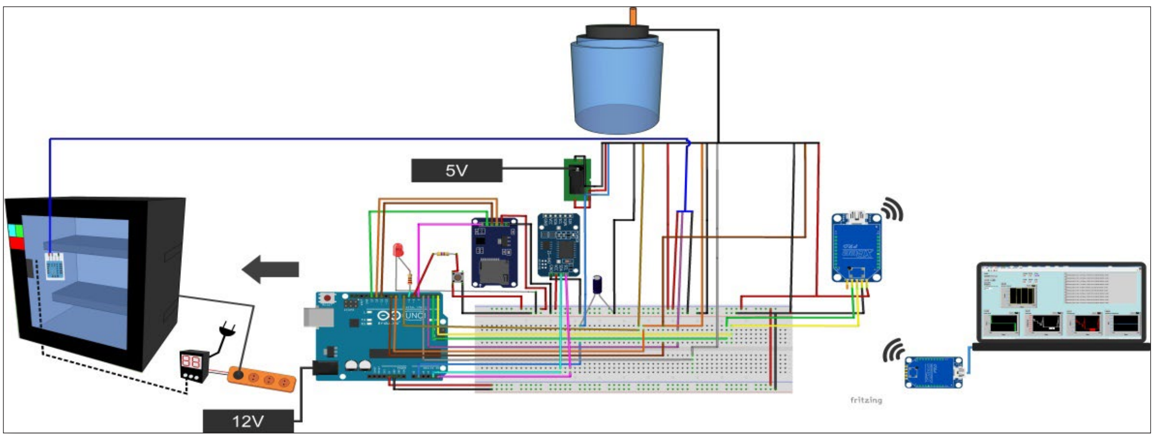

Figure 1. Fruit respiratory chamber

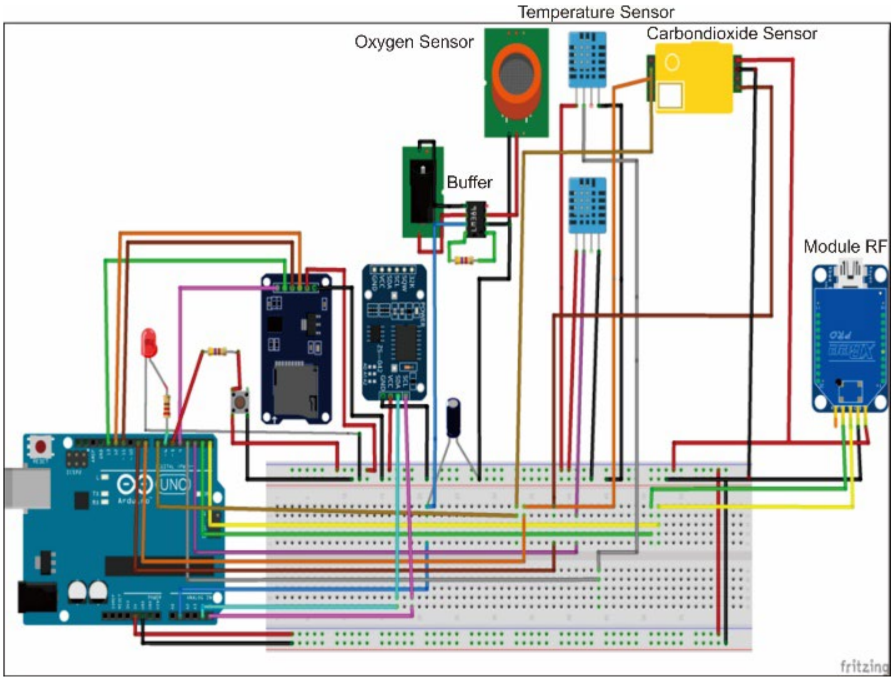

Figure 2. Respiratory chamber wiring diagram

Respiratory Chamber

A permeable glass bottle jar with free space volume at 3,600 mL was used for the respiratory chamber design (Surabaya, Indonesia). The respiration rate investigation was supported by the embedded three sensors; for oxygen, carbon dioxide, and temperature. The micro holes around embedded sensors were sealed using an adhesive sealant to prevent gas leakage that might lead to a bias in data measurement. Sensors instruments and devices were powered and controlled by a microcontroller with data logger module (González-buesa and Salvador 2019). However, this study applied a wireless sensor to transfer data measured and then stored in SD card and computer hard disk. The respiratory chamber overview is illustrated in Figure 1, while the wiring diagram and sensor placements are presented in Figure 2.

Respiration Rate

Two methods are usually used to observe oxygen consumption and carbon dioxide formation in fresh fruit and vegetable respiration namely gas chromatography and infrared/electrochemical gas analyzer (Lokke *et al.*, 2011). The oxygen uptake and carbon dioxide production rate can be assessed using some mathematical models as shown in equations 1 and 2.

$$R_{O_2} = V \frac{([O_2]-[O_2])}{(t_2 - t_1)} \frac{1}{100\ W} \quad (1)$$

$$R_{CO_2} = V \frac{([CO_2]-[CO_2])}{(t_2 - t_1)} \frac{1}{100\ W} \quad (2)$$

Where, and are oxygen and carbon dioxide concentration (%), and are times (minute), W is the sample product weight (kg), and V is the free volume inside the respiratory chamber (mL). The oxygen and carbon dioxide concentrations were directly measured by the respective sensors in (%) unit.

Experimental Procedure

A low-budget respiration chamber was tested for measuring the respiration rates at different storage temperatures namely 12 °C; 18 °C and 33 °C. *Harumanis mangoes* were filled into a bottle jar and closed the lid, then the interface was turned on to start the measurement. Empty bottle jar was used as a control variable, while those containing mangoes in different temperatures were utilized to measure changes in oxygen and carbon dioxide concentrations during storage. Measurements for determining the respiration rates were carried out for 72 hours and replicated 3 times.

RESULTS AND DISCUSSION

Temperature profile

The respiratory chamber was supplied with refrigerants in the temperature range of 4 °C to 30 °C,

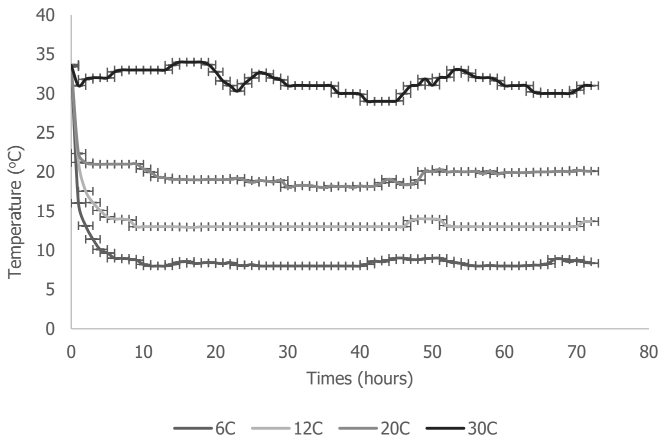

Figure 3. Temperature behavior in the respiratory chamber at various set-up points

and was regulated by Omron E5CWL where the wiring diagram followed the path provided by the manufacturer. Thermocouple have pin line number 4 (-) and 5 (+) while power supply was on 7 and 8. The cooling chamber power path was connected to the relay for disconnecting and connecting the refrigerant flow, thereby making the temperature consistent with the set-up point.

The low air temperature diffused uniformly into the wall of the bottle jar and conducted into the free space. The temperature was measured by a DHT11 sensor attached on the bottle lid to collect data from the respirometer. The temperature data inside the bottle jar is very important because it determines fruit sample respiration activity during storage. Therefore, the wireless network system applied collected two data types including cooling chamber and respirometer temperature.

Based on the results, the refrigerant maintained the steady temperature as set-up value or did not significantly show oscillating performance for 72 hours (Figure 3). The ambient temperature in the respiratory chamber ranged from 33.4 °C-33.7 °C but slight oscillation was displayed at tropical ambient temperature where the refrigerant kept the value between 33.0 °C - 33.5 °C. Consequently, the refrigerant must work to reduce the temperature effectively at setting point of 8 °C and 12 °C after 11 hours.

Low Budget Respiratory Wireless Sensor Network

Fruits and vegetables' respiration rates are usually determined using gas chromatography (Escalona *et al.*, 2006; Verlinden *et al.*, 2007; Helena Gomes *et al.*, 2010). Also, the gas analyzer is used for measuring oxygen and carbon dioxide concentration during fruit respiration (Torrieri *et al.*, 2009the effect of temperature, oxygen, red coloration process and post-harvest storage time on the respiration rate of fresh-cut Annurca apples was studied to properly develop modified atmosphere packaging. Our results showed that the red coloration process and the post-harvest storage time did not affect the respiration rate or the respiratory quotient of fresh-cut Annurca apples in the range of temperature studied (5-20 °C; Iqbal *et al.*, 2009). These previous methods are popular, but they produce data that do not accurately reflect oxygen consumption and carbon dioxide release. Meanwhile, a wireless sensor network is a system comprised of radio frequency (RF) transceivers, sensors, microcontrollers, and power sources. Several types with self-organizing, self-configuring, self-diagnosing, and self-healing capabilities have been developed to solve problems or to enable applications that traditional technologies cannot address (Wang *et al.*, 2006). This network system was applied in this study to provide real-time oxygen and carbon dioxide concentrations during fruit respiration. The gas concentration and temperature inside glass jar as well as the cooling box were continuously measured by sensors.

The oxygen sensor KE25F3 was amplified with an Op-amp INA 122p up to 48.2 times with a resistor at 4.26 kΩ. The sensor did not pass through the microcontroller but was directly connected with the arduino ground pin serial bus. Meanwhile, the carbon dioxide sensor MH-Z19 was applied with two signal outputs namely UART (with arduino pin 7 and 8, as well as PWM at 9A wireless system was then used to monitor both oxygen consumption and carbon dioxide release during storage where a microcontroller was connected with Xbee 2.4 GHz serial. Under this condition, the respiratory chamber system detected the gas concentration without any internet connection but manually from micro-SD storage.

A low-budget respiratory wireless sensor was used to measure fresh air in a trapped bottle jar. The sensor read oxygen concentration at 20.9%, carbon dioxide 0.039% or 390 ppm and the tropical ambient temperature at 32 °C. This measurement was used to optimize the sensor performance in the permeable glass jar. All sensors showed constant measurements for 10 hours indicating that the instrument worked properly for transferring data from the respiratory bottle jar to the computer interface. Furthermore, it was observed that the respiratory chamber produced a low deviation number. The temperature deviation was calculated at 2.34%; oxygen 0.42%, and carbon dioxide 0.92%. The interface was built using open source program based on GUI labview to support graphical monitoring. Satability of the sensors plays a role in generating data during

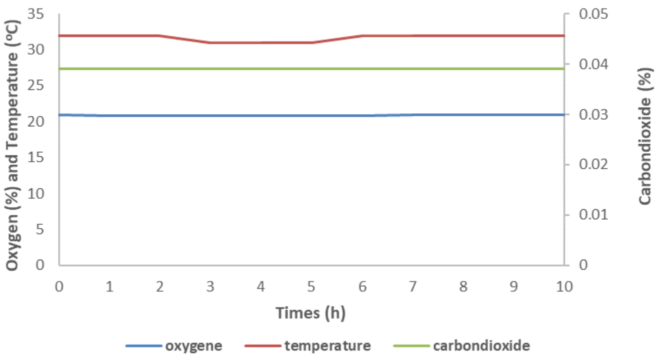

Figure 4. Wireless sensors measurement in a respiratory bottle jar

measurement of the metabolic process during storage. Lokke *et al.* (2011) mentioned that the sensors enable a very fine-tuned and continuous determination of temperature profile.

Respiration Rate

The *Harumanis mango* continued to respire after harvest and during storage as demonstrated by the consumption of oxygen from the air surrounding the bottle jar. During respiration, the dry matter was decomposed into carbon dioxide and H_2O with a release of heat. The oxygen and carbon dioxide composition were recorded at different temperatures as shown in Figure 5 The oxygen consumption trend was reciprocal with carbon dioxide production. This result is consistent with a previous study which stated that excessive carbon dioxide release inhibited oxygen uptake (Castellanos *et al.*, 2016).

Temperature differences have been shown to influence *Harumanis* respiration behaviorBased on the results, an increase in the temperature elevated oxygen consumption and carbon dioxide production. The effect on carbon dioxide release was more significant at higher storage temperatures. Initial oxygen and carbon dioxide concentrations in the glass jar were 20.67% and 0.04% or 385 ppmwhich are close to the normal atmospheric values. During storage, the oxygen consumption is high at the initial period due to the large amount of available for respiration activities. The trends were also higher at the beginning in most fruits such as tomatoes in MAP (Fagundes *et al.*, 2015), and carrots (Iqbal *et al.*, 2009). Subsequently, an equilibrium was achieved when no further oxygen consumption occurred. The steady respiration was achieved faster under lower storage temperature conditions where constant oxygen consumption occurred at 2 hours, 7 hours, and 19 hours storage period at 12 °C; 18 °C; and tropical ambient temperature of 33 °C, respectively. Banganapalli and

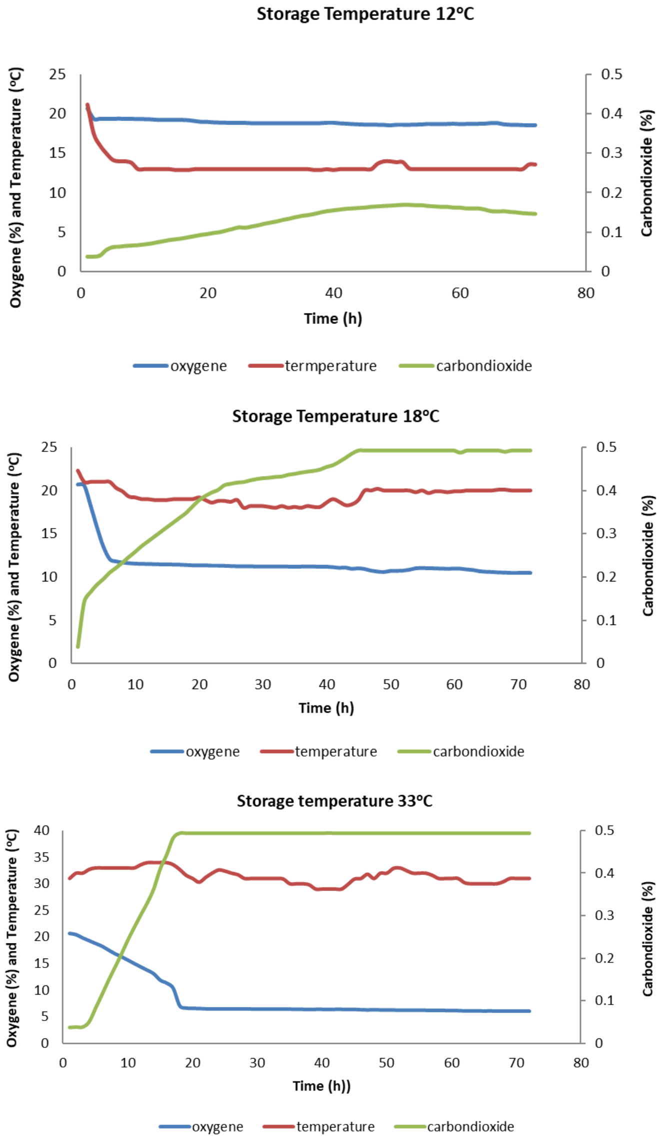

Figure 5. Respiration data acquisition measurement at storage temperature: a) 12 °C, b) 18 °C, and c) 33 °C

Thotapuri mango varieties reached an equilibrium in oxygen uptake after 6 hours storage period at 12 °C (Devanesan *et al.*, 2012). Meanwhile, carbon dioxide release increased rapidly for few hours, while constant production was attained earlier at higher.

Based on experimental data, the respiration rate at different temperatures influenced oxygen uptake and carbon dioxide release. The increasing rate indicates a shortened shelf-life (Agudelo and Restrepo, 2016). When the temperature was lowered, the storage period significantly reduced with the oxygen remaining at a higher concentration and a lower level of carbon dioxide level being released. The increasing temperature accelerated the respiration rate (Lokke *et al.*, 2011). The result showed that the oxygen respiration rate

(RRO_2) was 6.28 mL $kg^{-1}h^{-1}$17.23 mL $kg^{-1}h^{-1}$and 25.76 mL $kg^{-1}h^{-1}$ at 12 °C, 18 °C, and 33 °C or ambient temperatureMeanwhile, the carbon dioxide respiration rate ($RRCO_2$) was 2.02 ml $kg^{-1}h^{-1}$, 6.83 mL $kg^{-1}h,^{-1}$and 11.26 mL $kg^{-1}h^{-1}$ respectively. The RO_2 increased by nearly 2.7 folds at 12 °C to 18 °C and 4.1 times from 12 °C to 33 °C for 72 hours storage period. The RO_2 is between 4 and 5 times for coriander, cluster beans, and beetroot when stored at 10 °C to 30 °C (Waghmare *et al.*, 2013), while the RCO_2increased by 3.4 times from 12 °C to 18 °C and 5.6 times from 12 °C to 33 °C for 72 hours storage period.

The respiratory quotient (RQ) was measured from the ratio of carbon dioxide to oxygen respiration rate. Based on the results, the RQ value ranged from 0.32 to 0.44. The increasing value indicates the presence of lower free oxygen in the bottle jar that can be used for aerobic respiration. Storage at 12 °C produced the lowest RQ but did not show anaerobic respiration because the oxygen concentration remained at 18.55%. This value is lower due to the cooler storage temperature which reduced the respiration rate.

CONCLUSION

A low-budget respiratory chamber was designed to measure the oxygen uptake and carbon dioxide production in *Harumanis* mangoe storage. The wireless network sensors on the lid of the glass jar were used to record and transfer respiration data with Xbee, while the GUI LabVIEW interface software facilitated real-time measurements. Based on the results, the respirometer is applicable for economical fresh fruit and vegetable storage due to the continuous and non-invasive process of determining the respiration activities without any reagent or additional sophisticated device. A reduction in the storage temperature decreased the respiration rate and RQ value. Furthermore, the results showed that the cooling chamber maintained the set-up temperature constantly at 6 °C, 12 °C, 20 °C, and 30 °C while the deviation range between 2.68 to 4.73%. An increase in the storage temperature accelerated both oxygen and carbondioxide respiration rate where the $RRCO_2$ was elevated 5.6 times for 72 hours and RRO_2 by 4.1 times from 12 °C to 33 °C.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

Agudelo, Camilo, and Caludia Restrepo. 2016. "Respiration Kinetic of Mango (Mangifera Indica L.) as Function of Storage Temperature." *Revista Facultad Nacional de Agronomia* 69(12):7985–95.

Barbosa, Neves, Bruno Augusto, Mattar Carciofi, Cristiano Édio Dannenhauer, and Alcilene Rodrigues Monteiro. 2011. "Influence of Temperature on the Respiration Rate of Minimally Processed Organic Carrots (Daucus Carota L . Cv . Brasília)." *Ciência e Tecnologia de Alimentos* 2009(003836):78–85.

Belay, Zinash A., Oluwafemi J. Caleb, and Umezuruike Linus. 2016. "Modelling Approaches for Designing and Evaluating the Performance of Modi Fi Ed Atmosphere Packaging (MAP) Systems for Fresh Produce : A Review." *Food Packaging and Shelf Life* 10:1–15.

Bhande, S. D., M. R. Ravindra, and T. K. Goswami. 2008. "Respiration Rate of Banana Fruit under Aerobic Conditions at Different Storage Temperatures." *Journal of Food Engineering* 87(1):116–23.

Bochtis, Dionysis D., Claus G. Sørensen, Ole Green, and Thomas Bartzanas. 2011. "A Diagnostic System for Improving Biomass Quality Based on a Sensor Network." *Sensors* 11(5):4990–5004.

Caleb, Oluwafemi J., Pramod V Mahajan, Fahad Al-julanda Al-said, and Umezuruike Linus Opara. 2013. "Modified Atmosphere Packaging Technology of Fresh and Fresh-Cut Produce and the Microbial Consequences — A Review." *Food Bioprocess Technol* 6:303–29.

Castellanos, Diego A., Josep P. Cerisuelo, Pilar Hernandez-muñoz, Anibal O. Herrera, and Rafael Gavara. 2016. "Modelling the Evolution of O2 and CO2 Concentrations in MAP of a Fresh Product : Application to Tomato." *Journal of Food Engineering* 168:84–95.

Coronel-Reyes, Julian, Ivan Ramirez-Morales, Enrique Fernandez-Blanco, Daniel Rivero, and Alejandro Pazos. 2018. "Determination of Egg Storage Time at Room Temperature Using a Low-Cost NIR Spectrometer and Machine Learning Techniques." *Computers and Electronics in Agriculture* 145(September 2017):1–10.

Devanesan, Jacinth Nithya, Alagusundaram Karuppiah, and C. V. Kavitha Abirami. 2012. "Effect of Storage Temperatures , O 2 Concentrations and Variety on Respiration of Mangoes." *Journal of Agrobiology* 28(2):119–28.

Escalona, Víctor H., Bert E. Verlinden, Sabine Geysen, and Bart M. Nicolaï. 2006. "Changes in Respiration of Fresh-Cut Butterhead Lettuce under Controlled Atmospheres Using Low and Superatmospheric Oxygen Conditions with Different Carbon Dioxide Levels." *Postharvest Biology and Technology* 39(1):48–55.

Fagundes, C., K. Moraes, M. B. Pérez-gago, L. Palou, M. Maraschin, and A. R. Monteiro. 2015. "Postharvest Biology and Technology Effect of Active Modi Fi Ed Atmosphere and Cold Storage on the Postharvest Quality of Cherry Tomatoes." *Postharvest Biology and Technology* 109:73–81.

Fonseca, Susana C., Fernanda A. R. Oliveira, and Jeffrey K. Brecht. 2002. "Modelling Respiration Rate of Fresh Fruits and Vegetables for Modified Atmosphere Packages: A Review." *Journal of Food Engineering* 52(2):99–119.

González-buesa, Jaime, and María L. Salvador. 2019. "An Arduino-Based Low Cost Device for the Measurement of the Respiration Rates of Fruits and Vegetables." *Computers and Electronics in Agriculture* 162:14–20.

Green, Ole, Esmaeil S. Nadimi, Victoria Blanes-Vidal, Rasmus N. Jørgensen, Ida M. L. Dreje. Storm, and Claus G. Sørensen. 2009. "Monitoring and Modeling Temperature Variations inside Silage Stacks Using Novel Wireless Sensor Networks." *Computers and Electronics in Agriculture* 69(2):149–57.

Helena Gomes, M., Randolph M. Beaudry, Domingos P. F. Almeida, and F. Xavier Malcata. 2010. "Modelling Respiration of Packaged Fresh-Cut 'Rocha' Pear as Affected by Oxygen Concentration and Temperature." *Journal of Food Engineering* 96(1):74–79.

Iqbal, Tariq, Fernanda A. S. Rodrigues, Pramod V Mahajan, and Joe P. Kerry. 2009. "Mathematical Modeling of the Influence of Temperature and Gas Composition on the Respiration Rate of Shredded Carrots." *Journal of Food Engineering* 91(2):325–32.

Lokke, Matte Marie, Helene Fast Seefeldt, Gareth Edwards, and Ole Green. 2011. "Novel Wireless Sensor System for Monitoring Oxygen, Temperature and Respiration Rate of Horticultural Crops Post Harvest." *Novel Wireless Sensor System for Monitoring Oxygen, Temperature and Respiration Rate of Horticultural Crops Post Harvest* 11:8456–68.

Mathupala, Saroj P., Sam Kiousis, and Nicholas J. Szerlip. 2016. "A Lab Assembled Microcontroller-Based Sensor Module for Continuous Oxygen Measurement in Portable Hypoxia Chambers." *PLoS ONE* 11(2):1–14.

Tanner, David. 2016. *Impacts of Storage on Food Quality*. Elsevier.

Torrieri, Elena, Silvana Cavella, and Paolo Masi. 2009. "Modelling the Respiration Rate of Fresh-Cut Annurca Apples to Develop Modified Atmosphere Packaging." *International Journal of Food Science and Technology* 44(5):890–99.

Verlinden, Bert E., Francisco Art, Bart Nicola, and Francisco Art. 2007. "Respiration Rates of Fresh-Cut Bell Peppers under Supertamospheric and Low Oxygen with or without High Carbon Dioxide." *Postharvest Biology and Technology* 45:81–88.

Waghmare, R. B., P. V Mahajan, and U. S. Annapure. 2013. "Postharvest Biology and Technology Modelling the Effect of Time and Temperature on Respiration Rate of Selected Fresh-Cut Produce." *Postharvest Biology and Technology* 80:25–30.

Wang, Ning, Naiqian Zhang, and Maohua Wang. 2006. "Wireless Sensors in Agriculture and Food Industry - Recent Development and Future Perspective." *Computers and Electronics in Agriculture* 50(1):1–14.

Willett, Martin. 2014. "Oxygen Sensing for Industrial Safety - Evolution and New Approaches." *Sensors (Switzerland)* 14(4):6084–6103.