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The Effect of Temperature on Quality of Climacteric Fruit in Cold Chain

Myo Min Aung, Dechrit Maneetham

[1]*Department of Robotics and Mechatronics Engineering, Faculty of Technical Education*
Rajamangala University of Tehnology Thanyaburi, Pathumthani, Thailand

Abstract: Temperature is the key to keep the quality and integrity of product after harvest in cold chain. The effect of temperature on climacteric fruits is demonstrated by climacteric characters such as the changes in respiration rate, colour, texture and flavor etc. The climacteric character represents an important determinant of the ripeness, maturity and storability. Banana is known as a tropical, climacteric fruit that presents fast post-harvest ripening; therefore, it is a very perishable product. Inappropriate storage temperature and retail practices can accelerate the quality loss of banana. Therefore, it should be maintained under properly controlled-temperature not to lose the quality throughout the supply chain. The objective of this paper is to evaluate the quality of banana during their ripening period by monitoring their respiration process and closely watching skin colour changes over time.

Keywords: cold chain, temperature, Banana, ripening, metabolism, respiration, colour, quality, deterioration

1. Introduction

Temperature is the characteristic of the post-harvest environment that has the greatest impact on the storage life of perishable food products. In tropical and subtropical regions, post-harvest losses of horticultural crops are estimated to be more than 50% of the production due to poor post-harvest handling techniques such as bad temperature management [1]. Therefore, cold chain or temperature-controlled supply chain play an important role to store and deliver safe and quality food to customers. Some varieties of fruit and vegetables have rates of respiration which do not decline during their ripening period. Therefore, produce may be categorised as climacteric that continues to ripen postharvest and non-climacteric that doesn't have that process. The ripening processes include development of colour, texture (tissue softening) and flavor [2]. Some climacteric fruits produce a burst of Ethylene gas, a trigger for ripening process. The rise in temperature contributes to increase both respiration and ethylene emission rate that accelerate product deterioration. Temperature abuse is a function of time and temperature during holding and the relative perishability of a particular commodity [3].

Good temperature management is, in fact, the most important and simplest procedure for delaying the deterioration of food products. In addition, storage at the optimum temperature retards aging of fruit and vegetables, softening, and changes in texture and color, as well as slowing undesirable metabolic changes, moisture loss, and loss of edibility due to invasion by pathogens. Temperature is also a factor that can be easily and promptly controlled [4]. Sometimes, the degradation of food is readily visible as changes of texture or discolouration, such as the blackening of banana skins as the fruit ripen passes peak ripeness. Bananas are harvested green and begin ripening as soon as the banana stem is cut from the plant [5]. In this paper, Banana is chosen as a sample fruit to monitor the respiration process and physical changes during their ripening and deterioration stages under different storage temperatures.

2. Respiratory Metabolism

Fresh fruit and vegetables are living products. After harvest, they continue the process of respiration which produces carbon dioxide, water and heat. In climacteric fruit, the respiration typically rises very rapidly during ripening, and then decreases as the fruit age after its maturity. The rate of deterioration of the produce is largely determined by the rate of respiration which is temperature dependent. Slow respiration rate can minimise product deterioration but respiration can never be completely stopped. Produce which is kept cool will have a low rate of respiration with limited heat production and low rate of deterioration. Different products have different rates of respiration. Those with higher rates are more highly perishable and temperature control is very critical for these products. Ethylene is produced by many plant products and can trigger ripening and deterioration in some products. Keeping products cool reduces the production of ethylene. Also, cooled products are less sensitive to ethylene [6]. The climacteric and non-climacteric pattern in respiration of fruits are represented by the following Fig.1.

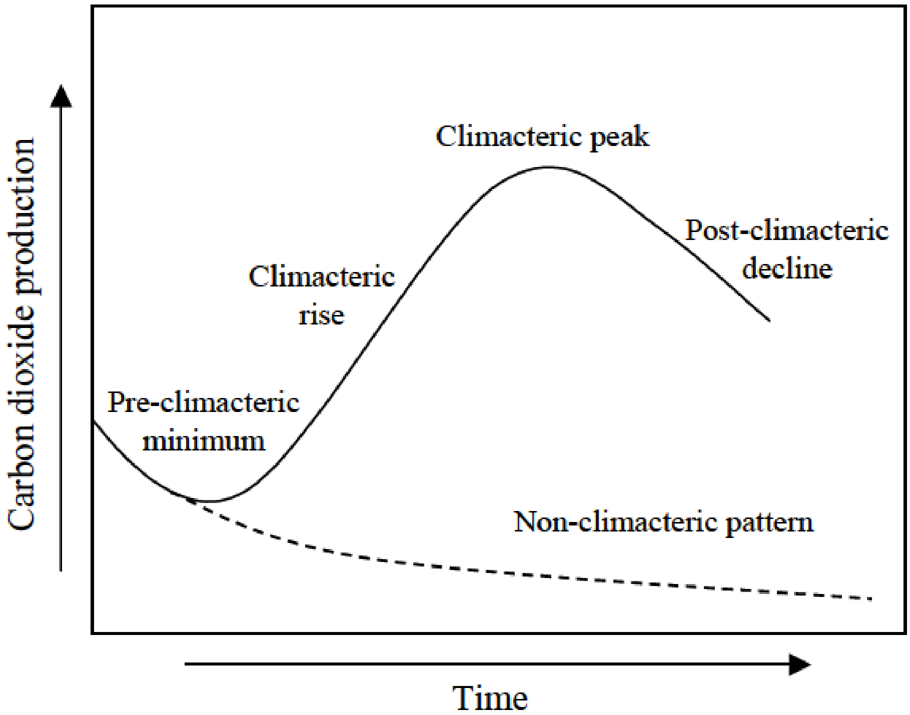

Fig. 1. The climacteric and non-climacteric pattern of respiration in ripening fruit [7]

In general, the storage life of commodities varies inversely with the rate of respiration. This is because respiration supplies compounds that determine the rate of metabolic processes directly related to quality parameters, eg., firmness, sugar content, aroma, flavor, etc. Measurements of respiration provide an easy, non-destructive means of monitoring the metabolic and physiological state of tissues. Aerobic respiration can be seen as follows in equation (1) [7]:

Glucose + Oxygen -> Carbon Dioxide + Water + Energy

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 686\ \text{kcal/mole} \quad (1)$$

3. Material and Method

A. Sensor Network Monitoring Platform

Sensors can be used to track, trace, and monitor environmental aspects of the products that are important to the quality management of perishable products. Wireless sensor network provide a flexible and powerful solution to monitor and control the cold chain at different levels of the logistical chain. Refrigerated vehicles can be a crucial point as the products may undergo transient conditions during transport and distribution process. Therefore, convenient and reliable monitoring systems are increasingly demanded for vehicle refrigerators. Wireless sensors are used in refrigerated vehicles to detect, identify, log, and communicate the real-time status of perishable products in transport through monitoring [8]. More intelligence could be achieved by combining wireless sensor networks with other technologies such as RFID and agents [9-10]. Sensors are not only placed in refrigerated room or container but also attached to the products itself (for e.g. wine or milk bottles etc.) using specially designed sensor nodes to detect environmental conditions more accurately [11-12]. ZigBee protocol is considered as the best candidate as it satisfies reliable, low cost and low power consumption requirements [13]. The previous researches mentioned above mainly focused on monitoring and performance issues of wireless sensor network in food industry rather than quality assessment under the effect of temperature.

We deploy a wireless sensor network which focuses on low-cost, low-power and high modularity in order to monitor banana in a refrigerator that is designed for experiment. We use the Texas Instruments's MSP430 ultra low power microcontrollers which are embedded with 2.4 GHz IEEE 802.15.4 / ZigBee-ready RF Transceiver. Environmental Board (EB), which consists of temperature/humidity, Carbon Dioxide (CO_2) and Ethylene (C_2H_4) sensor are integrated into sensor node's design. Also, a Base Station (BS) is designed to collect real-time data which are passed from sensor nodes and forward back to terminal PC's Application Programming Interface (API) through serial port. Furthermore, one sensor Control Board (CB) is embedded to refrigerator to monitor and control room temperature. The TinyOS, event-based operating environment/framework which is designed for use with embedded networked sensors is the main platform used in this system. The communication scheme for sensor data acquisition and reporting process of sensor network is graphically shown in Fig. 2.

First of all, sensor nodes are placed with banana sample together in the rooms of refrigerator. A few communication steps need to be done to receive the data reported from sensors in desired time interval and required settings. Firstly, the communication to BS is initiated. The acknowledgement returned form BS shows the current working status of BS and other sensors. Secondly, sending request to CB is done after setting up the reporting interval and the required target temperature for refrigerated rooms. Thirdly, the required report interval for specific sensor is set in sending request packet which is destined to EBs. Finally, the required data values in hexadecimal format are extracted from reported data packets for further analysis.

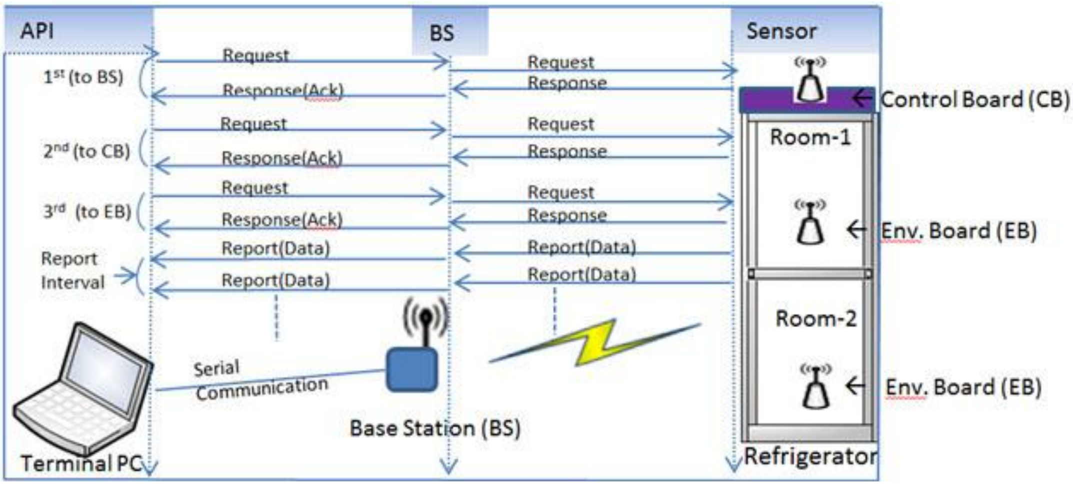

Fig. 2. Sensor data acquisition and reporting process

B. Respiration Rate Measurement

Four sample of Cavendish banana (Musa acuminate, AAA group) were stored in each temperature controlled chamber at 13, 16 19 and 22°C for 24 hours period. 13°C -16°C is the optimal temperature range to store ripe banana. Fig. 3 demonstrates acceleration or deceleration of the ripening process of a banana through monitoring, especially on temperature’s effects over respiration rates. The experimental result shows that respiration rates (CO_2 emission) are temperature-dependent.

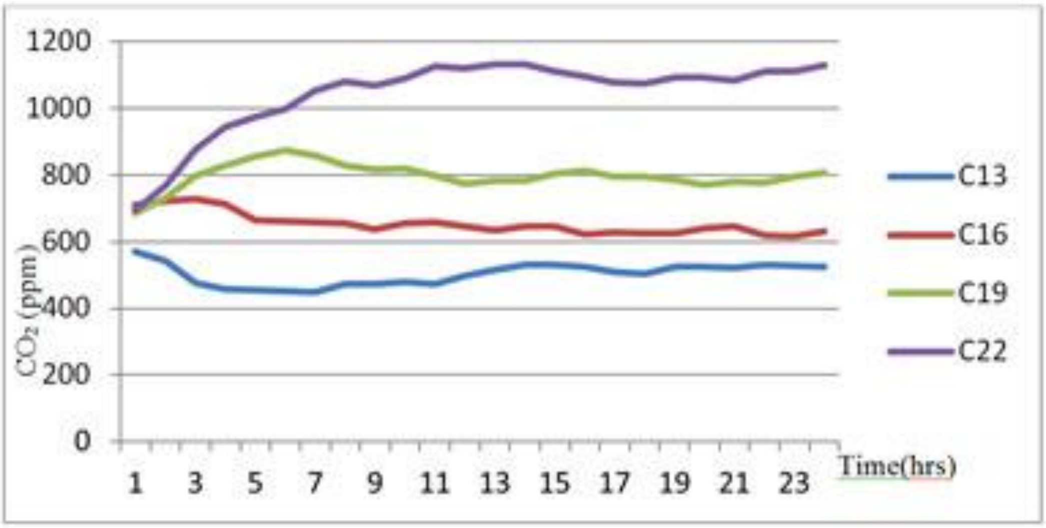

Fig. 3. Changes in respiratory rate of banana under different storage temperatures

C. Quality Evaluation in term of Freshness

Freshness is one of the most important aspects of fresh, especially frozen and chilled foods. In this paper, the freshness of the produce is considered as an important attribute of quality evaluation. Initially, the current Freshness Gauge (FG) of a good product item is assumed to be 100 %. FG value can be changed over whenever the temperature rises. FG is calculated based on product shelf life and current temperature value received from temperature sensor. The value of FG can be calculated as follows:

$$FG = FG - \frac{(CLT - PLT)}{((ST - MT) * WS)} * 100 \qquad (2)$$

Where, FG = Freshness Gauge, CLT= Current Log Time, PLT = Previous Log Time, ST = Sell-By Date time, MT = Manufacturing/ Harvest Date time, WS = Weight of Shelf Life/ Deterioration Rate.

Typically, the original shelf life (ST-MT) will decrease over storage time. The shelf life of an item can be reduced more if temperature goes up from optimal range of a specific product. We considered the period how long the temperature abuse happened in our formulation. As time goes on with temperature above optimal range, the FGwill go down with respect to the values of weight (WS). Over the physiological range of most crops, i.e., 0 to 30 °C (32 to 86 °F), increased temperatures cause an exponential rise in respiration. The Van't Hoff Rule states that the velocity of a biological reaction increases 2 to 3-fold for every 10 °C (18 °F) rise in temperature. Therefore, we adopt the Q_{10} factor as the indicator to evaluate the quality change during storage of perishable products. The calculation of Q_{10} is as follows. We use CO_2 sensors to monitor the respiration rates at different temperatures. Q_{10} shows that different temperatures have impacts on the rates of respiration or deterioration and relative shelf life of a typical perishable commodity. For example, if a commodity has a mean shelf-life of 100 days at 0 °C, then Q_{10}=2.0 at 10 °C simply imply that it can be stored no more than 50 days. Using this concept, the value for each WS is calculated [14].

D. Skin color measurement for ripening Banana

Colour is one of the most important quality attributes in postharvest food handling and processing, and it influences consumer's choice and preferences. Banana industry today use color charts to judge the skin color of banana. The color of the banana skin is used as an indicator for ripeness or spoilage. A peel color index (scale of 1-7) of banana are divided into 7 level; 1) Green, 2) Green-trace, 3) More green than yellow, 4)More yellow than green, 5) Green tip, 6)All yellow, 7)Yellow-flecked with brown [15]. In our experiment, we use four samples of banana (Cavendish group) which has peel color index no. 5. These color charts are useful to judge the peel colors of banana but inspector's decision on quality is rather visual (i.e., subjective) measurement. The instrumental (objective) methods are needed to determine more precisely over the maturity and quality of wide range of food products. There are some devices available such as Colorimeter or Chromameters for measuring reflected and transmitted color of objects. In [16], banana fruits were exposed to temperature of 20°C to 30°C to measure change in green colour in the banana peel. The greenness of the peel of ripening banana fruit, express as a* values (L*, a*, b* colour system) is measured with a Chromameter. The more negative the value of a*, the greener the appearance of the fruit.

Alternatively, digital imaging method is found to be useful in fresh produce industry to estimate the ripening stages of bananas more accurately [17]. In this paper, we propose a method to differentiate ripening skin colors of banana by using a software tool (i.e. Histogram of Adobe's Photoshop CS software). A histogram illustrates how pixels in an image are distributed by graphing the number of pixels at each color intensity level. The histogram panel offers many options for viewing tonal and color information about an image. Measurements were performed at arbitrarily chosen 2cm*2cm area of banana skin images that we recorded every 12 hrs to identify skin color changes of banana under 24-26°C room environment using histogram (Fig.4). Also the relative color intensity data are collected after measurement of seven consecutive images (Table1.). Then, the level of the ripeness could be easily determined by histogram matching of the measured and standard ripeness stages.

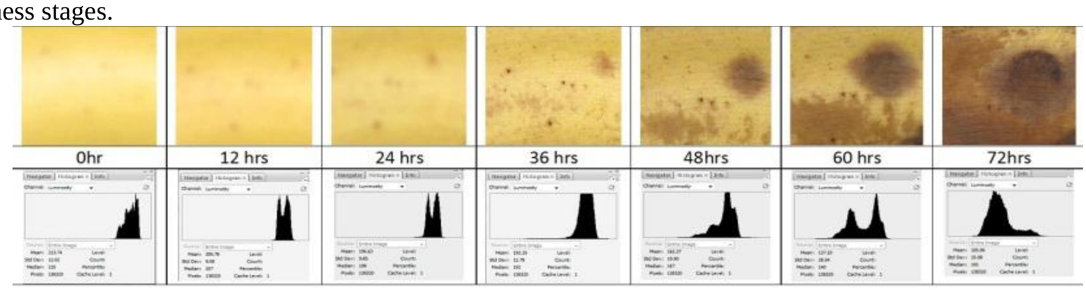

Fig. 4. Histograms regarding skin color changes of ripe banana over time

Table1. The empirical data regarding skin colour changes of ripe banana over time

Image No.	Luminosity	R	G	B	RGB
1	213.74	242.42	215.85	124.85	194.37
2	205.78	240.1	206.16	110.95	185.74
3	196.63	227.03	197.69	108.79	177.84
4	192.25	223.75	192.17	107.63	174.52
5	162.37	193.46	160.58	88.12	147.38
6	137.21	167.82	133.67	73.68	125.06
7	105.96	136.35	98.76	62.76	99.29

4. Conclusion

In this paper, we presented respiration rate and color identificationas two important factors in quality evaluation of perishable foods. Color identification techniques are especially useful for products in which colour is an important quality indicator. The importance of monitoring respiration rate of perishable food is highlighted testing Banana as a sample. To determine the quality status of perishables objectively, using more than one indicator is necessary. Other important environmental parameters such as humidity and ethylene emission etc. should be considered for further extension.

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