Storage Life of 'Fuji' Apple Stored in the Controlled Atmosphere Container

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***Abstract*—This study was carried out to indirectly predict the storage life, hardness, and acidity through respiration rate of Fuji apples in Controlled Atmosphere (CA) storage. A sensor installed inside the CA storage measured temperature, relative humidity, and gas composition data in real time. The respiration rate from five tons of apples in CA storage was calculated to predict the weight loss rate. As a result, the predicted and actual weight loss rate induced a predictable residual storage time equation that showed a very high correlation. The apple storage period showed a high reliability (R^2=0.9322) because the predicted equation using respiration rate and number of days stored was about nine months for five tons of apples. The hardness and acidity prediction equations were derive from the quality analysis. However, correlation coefficient of hardness and acidity was low as 0.3506 and 0.3144, respectively. It was caused by insufficient quantity of analytical samples, but the decrease tendency of acidity and hardness was confirmed from the equation. As a result, these quality prediction equations could encourage CA container distribution, effective for agricultural shipment regulation and increasing ease of operations.**

***Index Terms*—controlled atmosphere storage, storage life, respiration rate, apple storage**

I. Introduction

Most Korean farmers have significant misgivings about Controlled Atmosphere (CA) storage because they have no experience of CA storage and they could not check the quality of the produce from time to time inside a CA container. A quality prediction system of produce stored in CA container is necessary to spread CA storage technology in Korea and prevent produce damage caused by carbon dioxide and oxygen.

Research into quality prediction for the cold storage of fruits and vegetables has been focused on how variables such as temperature, relative humidity, oxygen level, and carbon dioxide level can influence produce quality [1], [2]. Most studies have been used to predict shelf life based on the temperature, because the model must be simple enough to be effective and not require too many inputs [3]. One simplified exponential model was $t = ae^{bt}$, where t = time in days until produce is unacceptable, a = a parameter describing shelf life at 0 ℃, b = a parameter describing changes based on temperature, and T = the storage temperature (℃) [4]. A more complex model not only depends on time and temperature, but also on storage atmosphere, respiration, ethylene level, and enzyme levels. This model was too complex and restrictive for use as a storage life prediction system based on real time data collected for produce in a reefer [5]. Another method was used to predict the green life for banana storage in an intelligent container during transportation. In this study, the function of temperature, humidity, and CA-conditions was used to describe the storability of bananas during transport [6].

Deciding the shelf life of fresh produce requires the definition of the maximum shelf life. In most studies, the maximum shelf life was defined as the weight loss of fresh produce [2]. Cauliflowers were used to predict shelf life in accordance with the variation in water loss, energy, and vitamin C content [1]. Seven percent water loss in apple weight loss can result in shriveling and a product finally losing its value [7]. Water is lost from fresh produce via transpiration. The process of transpiration includes the transport of moisture through the skin of the product, the evaporation of this moisture from the product surface and the convective mass transport of the moisture to the surroundings [2]. Another study also predicted shelf life from the correlated data between the storage time and water loss [8].

This study was carried out to indirectly predict the storage life, weight loss, hardness, and acidity through the respiration rate of Fuji apples in CA storage. This model will adapt to our newly developed CA container so that these quality prediction equations can encourage CA container distribution, effective agricultural shipment regulation, and increased ease of operations.

II. Materials and Methods

A. Fruit Samples

Apples (Fuji) that were harvested in October 2015 were purchased from a local farm in Jeollabuk-do, Korea. The weight of the apples was in the range 200–250 g. The total weight of apples was five tons and the experiment period was nine months.

B. Measurement of Respiration Rate

In The apple's respiration rate must be reduced to predict its storage life based on the respiration rate inside a CA container. Monitoring the temperature, relative humidity, oxygen, and carbon dioxide was carried out

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using multiple sensors (VT250-02, Soha-tech, Seoul, Korea) [9]. The delayed CA storage of apples is recommended to prevent carbon dioxide and oxygen damage in Korea. Water core disorder that caused the development of fresh browning in the apple disappeared during the 21 days of delayed CA storage in cold storage. The respective O_2 and CO_2 levels inside CA container were 20.9% and 0.03% during the 21 days of delayed CA storage, since then atmosphere of the CA container was maintained at 2% O_2 and 0.5% CO_2 for the next 90 days. After 90 days, the CO_2 level inside the CA container was maintained at below 1.0%. The respiration rate (R) of the apple was calculated using (1).

$$R(CO_2\%/t) = Y_1 \cdot X_1^{-1},\ Y_1 \cdot X_1^{-1},\ \cdots;\ Y_\chi \cdot X_\chi^{-1} \qquad (1)$$

$X_{1,2,\ \cdots;\ \chi}$: Storage time
$Y_{1,2,\ \cdots;\ \chi}$: Percent of carbon dioxide Respiration

C. *Apple Quality Measurement*

Weight loss during storage was determined by measuring the total weight in a container box on the first day and then at one month intervals throughout the storage period. The evaluation of apple firmness was performed at room temperature using a texture analyzer (TA-XT2, Stable Micro System Ltd., Godalming, UK) equipped with a puncture probe (5 mm diameter) to penetrate the apple's flesh. The probe speed for penetration 2 mm/s and downward movement to 10 mm. The puncture forces were taken as the maximum peak on the graph and expressed as a mean value of Newton (N) force from three replicate measurements per sample. Titratable acidity was calculated by the malic acid content using a pH analyzer (TitroLine 500, Si Analytics, Mainz, Germany). The homogenate samples (20 g) were measured for pH and then were titrated to pH 8.3 with 0.1 N NaOH and the acidity was calculated as malic acid on a weight basis from three replicate measurements per sample [10].

D. *Statistical Analysis*

Regression analysis was conducted to analyze the data with the SPSS 23 program (IBM Corp., Armonk, NY, USA). All results of respiration rate, hardness, and titratable acidity were expressed as average values to raise the reliability.

III. Results and Discussion

A. *Respiration Rate of Apples*

The change in gas concentration in storages was shown in Fig. 1. These results were expressed concretely CO_2 concentrations variations (Fig. 2). As a result, the respiration rate of the apple was 3.0 ml/kg·h after 21 days of storage and then slowly decreased to 1.1 ml/kg·h over the 100 days of storage [11]. This result meant that it was possible to predict the apple's storage life during CA storage.

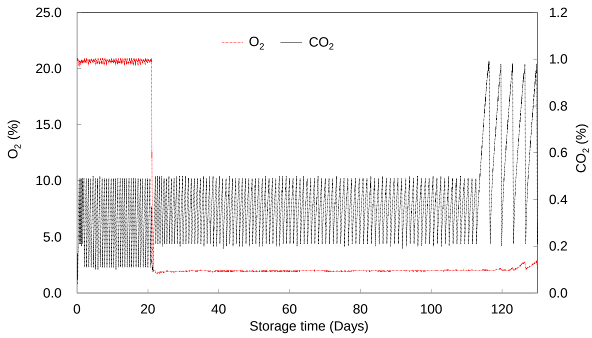

Figure 1. Variation of O_2 and CO_2 level inside CA container.

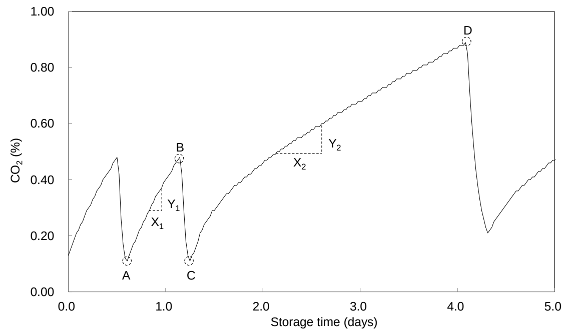

Figure 2. Slope of respiration rate inside CA container.

B. *Prediction of Weight Loss*

The weight loss of the apples was calculated using the transpiration coefficient (TS) and vapor pressure deficit, as in (2) [2]. The transpiration coefficient of the apples is 42 mg/kg·sec·MPa.

$$WLOSS = TS \text{ x } VPD \qquad (2)$$

$$VPD = VP_{apple} - VP_{air} \qquad (3)$$

$$VP_{apple} = 6.138\ e0.0698T \text{ x } 0.0001 \qquad (4)$$

$$VP_{air} = VP_{apple} \text{ x } (RH \text{ x } 0.01) \qquad (5)$$

WLOSS: Weight loss of apple (mg/kg·sec)
VPD: Vapor pressure deficit (MPa)
VP_{apple}: Vapor pressure of apple (MPa)
VP_{air}: Vapor pressure of air (MPa)
T: Temperature of CA container (℃)
RH: Relative humidity (%)

C. *Prediction of Maximum Storage Life*

"Fuji" apples were very high water content (84%) at harvest time [11]. After approximately 7% weight loss, the skin of the apple starts to shrivel and becomes unmarketable. Low water will create economic loss and more severe water loss results in a reduction in appearance quality, including shriveling, which will reduce the market value. Therefore, weight loss rate prediction was very important factors in the quality assessment. The maximum storage life of the apples was calculated by (6).

$$MSL = MLOSS / DLOSS \qquad (6)$$

$$DLOSS = (WLOSS/1{,}000{,}000) \text{ x } 100\text{x}86{,}400 \qquad (7)$$

$$TLOSS = DLOSS \times D \tag{8}$$

MSL: Maximum storage life (days)
MLOSS: Maximum weight loss of apple (7%)
DLOSS: Daily weight loss of apple (%/day)
WLOSS: Weight loss of apple (mg/kg·sec)
TLOSS: Total weight loss during CA storage (%)
D: Storage time (days)

The apples storage life was calculated by (9). The predicted storage time was calculated by the regression equation, which was derived from the relationship between storage time and the respiration rate as in Fig. 3. As a result, the simulation of 205 days from the CO_2 management stage 2 to the long-term storage stage 3, the SDAYS was derived from regression equation (10), which was a reasonable assumption that R^2 values was 0.9322.

$$SL = MSL - SDAYS \tag{9}$$

$$SDAYS = 0.0258R^{-2.584} \tag{10}$$

SL: Storage life (days)
MSL: Maximum storage life (days)
SDAYS: Predicted storage time (days)

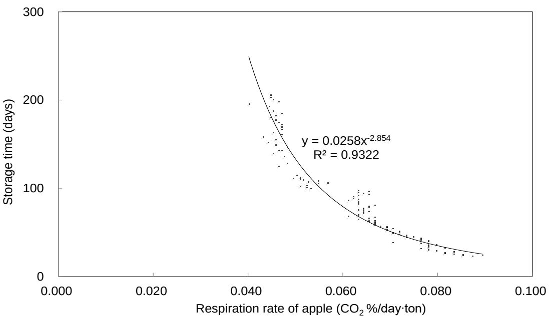

Figure 3. Prediction of storage days using respiration rate of apple inside CA container.

D. Prediction of Hardness and Titratable Acidity

Table 1 shows the hardness and titratable acidity of the apples, in which the predicted quality was compared with the actual quality of the apples during CA storage. Weight loss changed greatly from 0% to 3.34%, while the hardness of apples decreased slightly from 16.5 N to 14.7 N, and the titratable acidity also decreased slightly from 0.411% to 0.359%. The hardness (HNESS) and titratable acidity (ACID) of the apples was calculated by (11) and (12), which were derived from the real CA storage of apples over nine months as in Fig. 4.

TABLE I. CHANGES IN PHYSICOCHEMICAL QUALITIES OF FUJI APPLES DURING STORAGE

Storage time (day)	Hardness (N)	Acidity (%)
0	15.3±2.5[1)]	0.41±0.08
31	16.5±1.7	0.41±0.01
73	16.5±1.7	0.39±0.03
105	14.9±1.8	0.39±0.01
133	14.4±1.7	0.39±0.01
164	16.3±3.6	0.39±0.01
196	13.6±1.3	0.39±0.01
227	14.7±2.4	0.36±0.05
254	15.3±1.4	0.30±0.09

[1)] The values represent mean±SD for sixty experiments.

The respective correlation values (R^2) of hardness and titratable acidity were as low as 0.3506 and 0.3144. The low reliabilities was judged by CA storage period of 9 months was insufficient time to bring about a clear quality change of apples. According to Ref. [8] and [12], the predictability of the commerciality was derived from the decreasing tendency of the hardness and acidity of apple depending on the storage period. Therefore, the accuracy of the equations could be improved through follow-up research and by gathering more data.

$$HNESS = 20.378 \times D^{-0.06} \tag{11}$$

$$ACID = 0.5345 \times D^{-0.077} \tag{12}$$

HNESS: Hardness of apple (N)
ACID: Titratable acidity (%)
D: Storage time (days)

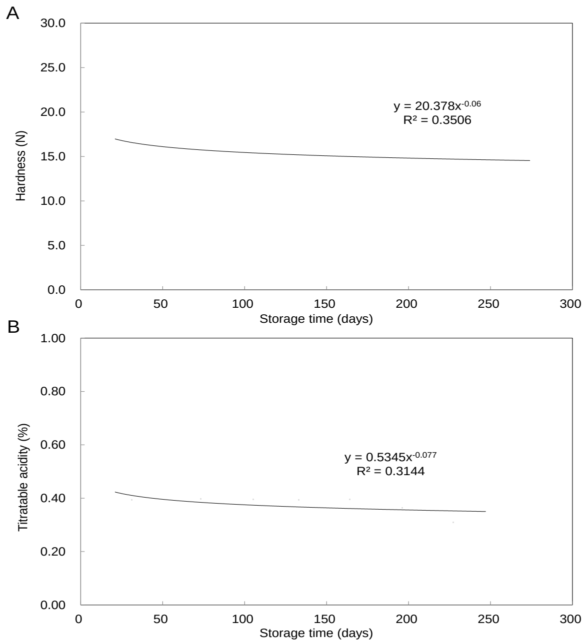

Figure 4. Prediction of hardness (A) and of titratable acidity (B) using storage days of apple inside CA container.

E. Control Algorithm for Prediction of Storage

Fig. 5 shows control algorithm for prediction of weight loss, storage life, hardness, and titratable acidity. All control data can be input automatically such as the temperature, relative humidity, oxygen level, and carbon dioxide level by the sensor inside the CA container excluding the amount of apples stored. The CO_2 concentration was detected within the range $0.3 \leq CO_2 \leq 0.4$ or $0.5 \leq CO_2 \leq 0.6$ with the all valves closed. TS and MLOSS were designed to be input according to separate research results and literature. As a result, SL, HNESS, and ACID were calculated in real time according to the change of R, and commerciality of apples in the CA storage was judged through the control panel. Thus, the quality prediction system based on the respiration rate can be applied not only to apples but also to various crops [13].

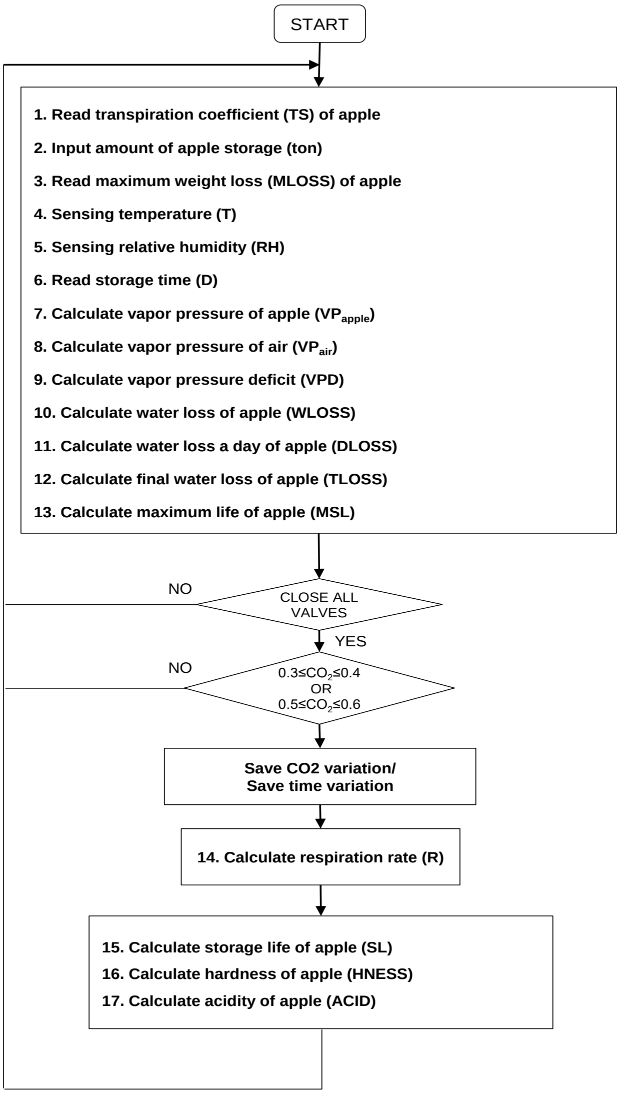

Figure 5. Control algorithm for prediction of storage life of apple inside CA container.

IV. Conclusions

The CA storage of Fuji apple showed that there is a small change in weight loss, texture, and chemical compositions [14]. However, CA storage do not check the quality of apples during the storage, therefore quality prediction system of CA storage apples seem to be need for the quality control [15]. This study is indirectly prediction the storage life, hardness, and acidity through respiration rate of Fuji apples in CA storage, but it is still inaccurate. We believe that, through further investigations, the quality prediction system would become a prospective system for fresh preservation of other fruit and vegetables.

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