Post-harvest Quality Evolution of Jonagored Apples (*Mallus domestica* cv. Borkh) during Shelf life Storage

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Abstract

The experiment was carried out to study the quality evolution of Jonagored apples (Mallus domestica cv. Borkh) during 14 days of shelf life prior to controlled atmosphere (CA) storage. The apple were harvested from the "Fruitteelt centrum" (Velm, Belgium) in 24 September 2010 (optimal picking) and 8 October 2010 (late picking) and were stored at 18°C and 65% RH to mimic the shelf life condition. The apple then were measured for colour, firmness, soluble solid content (SSC), titratable acidity, ethylene production rate, O_2 consumption rate, CO_2 production rate and respiratory quotient (RQ) at 0, 7 and 14 days after harvest.

There was a significant effect of shelf life duration in colour of the apple. The apple turn its colour from green to yellowish green at the end of shelf life. The optimal-harvested apple had a greener colour than the late-harvested apple at 0 and 7 days of shelf life except at 14 days where the older apple had a greener colour. Although the effect was not consistent, firmness of apple was affected by shelf life and picking time as well. Firmness decreased along shelf life and the optimal-harvested apples were firmer than the late-harvested apple. Apple's acidity decreased during shelf life from 8,43 mL NaOH (optimal-harvested apple) and 8.85 mL NaOH (late-harvested apple) to 7.58 mL NaOH (optimal-harvested apple) and 7.03 mL NaOH (late-harvested apple) at the end of shelf life. Yet, acidity was not affected by picking time. Ethylene was considerably increased throughout shelf life and the late-harvested apple had a higher ethylene production level than the optimal-harvested apple. Optimal-harvested apple had a lower respiration rate than the late picked apple. Older apple consumed oxygen and produced carbon dioxide at a higher rate than the younger apple. Moreover, respiration rates as represented by O_2 consumption rate, CO_2 production rate and respiratory quotient (RQ) tended to increase along shelf life.

Keywords: *Apple quality, storage, respiration*

1. INTRODUCTION

Quality of fruit are a whole intrinsic and extrinsic characteristics that meet the consumer needs. Quality relies on human perspectives comprising many properties or characteristics. Importance of some quality components depend upon the commodity and its intended use and varies between producers, handlers and consumers (Kader, 1999; Barrett *et al.*, 2010)

Maturity at harvest is of importance in determining storability and fruit quality at the final consumption. Caution must be taken carefully when harvesting the fruit. It should be picked at its optimum maturity otherwise it would be prone to some postharvest physiological disorder. Fruit that are picked too early are more susceptible to shriveling and mechanical damage and will have poor flavour quality when ripe. Overripe fruit are likely to become soft and mealy with insipid flavour soon after harvest.

During ripening, several considerable changes are taking place such are change in colour due to chlorophyll degradation or synthesis or unmasking of another colour pigments, softening which could be attributed to starch degradation and conversion to sugar, and flavour develoment due to alteration in sugar and organic acids

Colour change is the most obvious signal of ripening. It is probably the major criterion for consumer to recognize ripeness of the fruit. Therefore, colour measurement is an important means of quality assessment of food products. Fruit ripening and vegetable

yellowing frequently involve the unmasking of yellow-to-orange xanthophylls and carotenes by the disappearance of chlorophyll. Measurement of changes in pigments is important in understanding the physiology of ripening and senescence Many color scales have been developed, but the predominant scale used for fruits and vegetables is the Hunter "Lab" or its variant CIE L*a*b* (Abbott, 1999)

Firmness is the primary textural attribute measured in fruits and vegetables. Firmness is usually measured by destructive puncture tests, including handheld Effegi and mechanized Instron tests (Volz, et al., 2003). An indication of firmness is obtained by the force necessary to cause penetration of a standard probe a specified distance into the product.

In the early stage of maturation, starch accumulated in the fruit tissues are progressivelly hydrolised resulting in sweeteness improvement. Sugar are synthesised from starch as a result of polymeric breakdown, especially pectic substances and hemicelluloses. It affect both the taste and texture of produce.

Respiration is responsible for energy production and synthesis of many biochemical precursor necessary for growth and maintenance of living cells. Respiration is essentially the enzymatic oxidation of a wide variety of compounds like starch, sugars, and organic acids by means of molecular oxygen to water and carbon dioxide (Nicolaï *et al.*, 2005). Factors affect the rate of respiration are temperature, O_2 concentration, CO_2 concentration and exposure to ethylene. Alteration in one or all of the factors will have an impact on the respiration rates either increase or decrease (Kays & Paull, 2004)

Measurement or estimation of respiration rate can be based on determination of the change of every component of the respiration process (O_2, CO_2, water, and the respiration heat). Most frequently, the CO_2 production or O_2 consumption rate is measured. This is because the production of metabolic water is too small in comparison to the overall amount of water present in the product, and heat production measurements need to be carried out in adiabatic setups, which are not easy to realize (Nicolaï *et al.*, 2009).

Ethylene (C_2H_4) is a naturally produced, simple two carbon gaseous plant growth regulator that has numerous effect on growth, development and storage live of many fruit, vegetables, and ornamental crops in very low concentration, from part per million (ppm, µl l^{-1}) to part per billion (ppb, nl l^{-1}). It is flammable, readily diffuses within and from the tissue and its production is promoted by stress and wounding. This stress-induced ethylene can also accelerate fruit ripening. Harvested fruit and vegetables may be intentionally or unintentionally exposed to biologically active levels of ethylene and both endogenous and exogenous source of ethylene contribute to its biological activity (Saltveit, 1999; Taiz & Zeiger, 2002)

Ethylene accelerates fruit ripening and a dramatic increase in ethylene production closely related with initiation of ripening. In many fruits, ripening is characterised by a climacteric rise in respiration and ethylene production. Apples, bananas, avocados, mangoes, and tomatoes are examples of climacteric class of fruit. Exposure to ethylene has been shown to increase softening of some fruits even during cold storage. In apple, removal of ethylene from controlled atmosphere chambers has been shown to reduce softening of varieties such as 'Bramleys Seedling', and 'Golden Delicious' (Knee & Hatfield, 1981). The firmness of many ripening fruit and vegetables decreases after an ethylene treatment. In the short term this is beneficial especially when associated with ripening. But, in long term ripening can progress into senescence and the flesh can become too soft. By stimulating fruit ripening, ethylene enhances taste and flavour. Therefore, inhibition of C_2H_4 biosynthesis will inhibit not only ripening but also the production of characteristic aroma volatiles (Yahia, 1991). (Bower *et al.*, 2003) reported that storage of 'Bartlett pears' at either −1 or 2 °C with 3 different ethylene levels (0, 1, 5 or 10 µl l^{-1}) increased the incidence of physiological disorders. However, the effect of ethylene was minor compared with the influence of temperature.

In order to design an appropriate cold storage system for long time storage of apple under controlled atmosphere (CA) condition, study of apple's quality evolution and respiration characteristics in non-CA storage

condition should be carried out. Another importance of the study was to gain a data for comparison with after CA storage measurement.

2. MATERIAL AND METHODS

2.1 Material

Jonagored apples (*Mallus domestica* cv. Borkh) were harvested in September and October 2010 at the Fruitteelt centrum (Velm, Belgium). To investigate maturity effects on quality evolution during storage, apples were harvested at the commercial harvest time (24 September 2010) and a late harvest time (8 October 2010). After harvesting, apples were sorted and all the diseased, damaged, without stalk or too small ones were discarded. The sound apples were then randomized and kept at 18°C and 65% RH for 14 days to mimic the shelf life condition. At 0, 7 and 14 days of shelf life, the apple were measured for colour, firmness, soluble solid content, tiitratable acidity, ethylene production rate, O_2 consumption rate, CO_2 production rate and respiratory quotient (RQ).

2.2 Methods

The experiment was performed in the Flanders Centre for Postharvest Technology/Laboratory of Postharvest Technology, Department of Biosystem Katholieke Universiteit Leuven Belgium.

2.2.1 Colour

Colour is one of the parameters used to evaluated the quality change of apples during storage. The colour was measured at five random positions on the surface of each apple using a Minolta CM-2500D Spectrophotometer (Minolta Camera Co., Ltd). The results were averaged (Abbott, 1999).

This spectrophotometer expresses colours as precise numerical values, relying on advanced optoelectronic technology. It provides high accuracy and the ability to measure absolute colours. The apple is illuminated by two pulsed xenon lamps. Multiple sensor segments receive light (in the visible-light range) from the object and transmit information to the microcomputer. The microcomputer determined the spectral reflectance based on information from the spectral sensor. The results are displayed as numerical values in L*a*b colour space as shown in the figure below

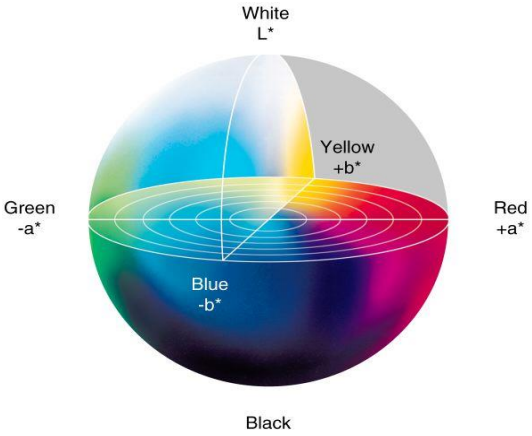

Figure 1. The L* Value Represents the Lightness of Apple on the Scale of 0 to 100

a* gives the values from green to red (-60 to +60)
b* gives the values from blue to yellow (-60 to +60)

2.2.2 Firmness

Fruit firmness was determined using a LRX material testing system (Lloyd Instruments Ltd) with a load cell of 500N. The firmness was calculated as the maximum force needed by a plunger with a surface of 1 cm^2 to penetrate the apple over a depth 8 mm with a speed of 8mm/s. The whole apple was placed on a cylindrical cup (instead of cutting it in to half). The firmness measurements were performed on two opposite sides of each apple. The results were averaged and expressed as kgf (Bullens, et al., 2010)

2.2.3 Soluble Solid Content

SSC was measured using a digital refractometer (Atago Co., Ltd). The measurement was done on two opposite sides of each apple. A juice sample was taken with a Pasteur pipette, put on the prism of the refractometer and push the start/off switch. The Brix value was recorded and the results were averaged (Peck, et al., 2006).

2.2.4 Titratable Acidity

Acid content was determined following methods of Peck et al (2006). Six apple composite sample were titrated by 10 ml of apple juice with 0,1 N Natrium hydroxide until pH = 8,1 was reached using a 702 SM Titrino (Metrohn Ion Analysis Metrohn Ltd).

The result were averaged and expressed as volume of NaOH 0,1 N consumed (ml NaOH 0,1 N)

2.2.5 Ethylene

The ethylene production rate is determined by following the method described by Bulens et al (2010). The apples were individually placed in airtight glass jars. Then it was flushed with humidified air for minimally 3 hours. Ethylene concentration of the headspace was determined by gas chromatography with Flame Ionisation Detector (FID, air flow : 300ml/min; H_2F flow : 35 ml/min) detection (Compact GC, Interscience, Louvain-la-Neuve, Belgium). The ethylene concentration from the GC is expressed in part per million (ppm). On the other hand, the ethylene production rate is expressed in nmol $kg^{-1}s^{-1}$. Therefore, to express ethylene in desired unit we convert ethylene concentration in ppm by using the ideal gas law

$$PV = n\,R\,T \qquad (2.1)$$

With *P* pressure of the gas (bar); *V* volume of the gas (m^3); *n* mol of the gas ; *R* is the gas constant (0.08314472 bar.m^3/kmol.K) and *T* is the absolute temperature of the gas (Kelvin).
The ethylene concentration from the GC is expressed in ppm

$$ppm\ C_2H_4 = \frac{n_{C_2H_4}}{n_{total}} \times 10^6 \qquad (2.2)$$

With $ppm\ C_2H_4$ is the ethylene concentration in ppm; $n_{C_2H_4}$ molarities of ethylene (mol/m^3) and n_{total} the total molarities of the gas (mol/m^3).
Substituting equation (3.2) to equation (3.1) resulting:

$$n_{C_2H_4} = \frac{ppm\ C_2H_4 \times 10^{-6} \times P}{R \times T} \qquad (2.3)$$

The rate of ethylene production is calculated from the difference of ethylene measured at time t_0 and $t_0 + \Delta t$ considering the apple mass (kg) and free space volume inside the jar. The free space volume was calculated by subtracting the fruit volume from the total jar volume. The apple volume was measured according to the water displacement method. The apple was immersed in a cup filled with water and the weight difference due to immersion was recorded. Using the density of water, which is a function of temperature, the volume of the apple is measured.

2.2.6 Respiration

Respiration rate measurement was carried out by measuring 0_2 consumption and CO_2 production of an individual apple inside the jar (Bullens, et al., 2010). The O_2 and CO_2 concentrations were determined by gas chromatography with Thermal Conductivity Detector (TCD) detection (Compact GC, Interscience, Louvain-la-Neuve, Belgium). The measured values of oxygen and carbon dioxide were expressed as percentage and then were converted to molar concentration according to ideal gas law.
The respiratory quotient (RQ) was calculated by :

$$RQ = \frac{V_{CO_2}}{V_{O_2}} \qquad (2.4)$$

With V_{CO_2} the carbon dioxide production rate; V_{O_2} the oxygen consumption rate.
The oxygen consumption rate V_{O_2} or the carbon dioxide production rate V_{CO_2} can then be calculated from

$$V_{O_2} = -\frac{V}{m}\frac{d}{dt}C_{O_2}(t) \cong \frac{V}{m\Delta t}\left(C_{O_2}(t_0+\Delta t) - C_{O_2}(t_0)\right) \qquad (2.5)$$

$$V_{CO_2} = -\frac{V}{m}\frac{d}{dt}C_{CO_2}(t) \cong \frac{V}{m\Delta t}\left(C_{CO_2}(t_0+\Delta t) - C_{CO_2}(t_0)\right) \qquad (2.6)$$

With *m* the mass of the product (kg); *V* the volume of the recipient minus the volume of the product (m^3); and C_{O_2} and C_{CO_2} the concentrations of O_2 and CO_2, respectively (mol/m^3).

The experimental design for comparing both optimal and late harvested apple was planned as a balanced 2-treatment factorial design and storage duration (0,7 and 14 days), Investigation to state significant difference between optimal harvest time and a late harvest time were carried out by the analysis of variance (ANOVA) procedure on the statistical program S-Plus (TIBCO Software Inc.,).

3. RESULTS

3.1 Colour

During shelf life the a*colour of the optimal-harvested apple gradually increased from -2.16 (day 0) to 1.60 (day 7) and 8.84 at the end of shelf life (day 14). Similarly, a*colour of the late-harvested apple also steadily increased from 3.01 (day 0) to 3.63 (day 7) and end up by 4.55. It was also revealed that at harvest the *a**colour of the late-harvested apple was higher than that of the optimal-harvested apple and that the late-harvested apple had always a higher *a** value during shelf life days. Interestingly, at the end of shelf lifeoptimal-harvested apple scored a higher *a**value than the late-harvested apple.

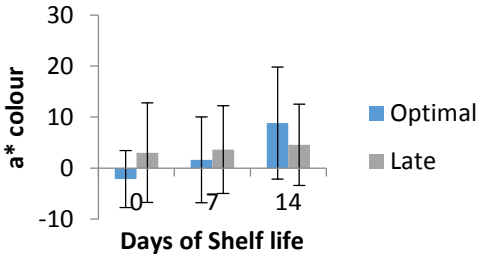

Figure 2. *a** colour evolution of Jongaored apples stored in shelf life condition for 0, 7 and 14 days

The change of b* value (Fig.2) was less prononcoued than that of the a* value. At 0 and 7 days no differences among picking time were found. It can be observed from figure that only at the end of shelf life, the late-harvested apple had a considerable increase in

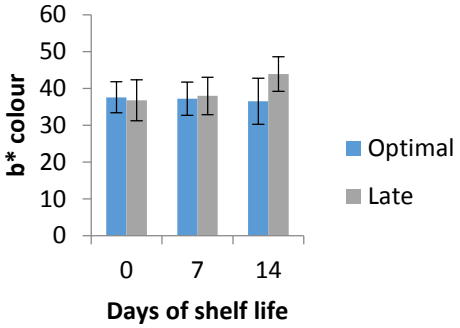

Figure 3. *b** colour evolution of Jongored apples stored in shelf life condition for 0, 7 and 14 days

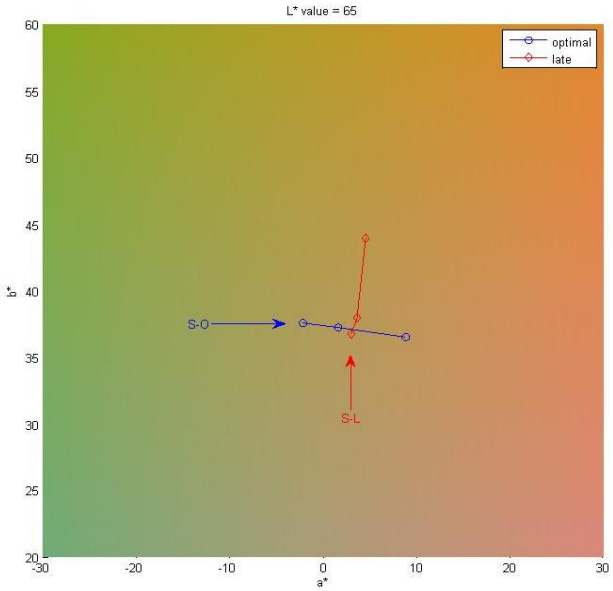

Figure 4. *a** and *b** colour coordinate shifting for the optimal (blue) and late-harvested apple (red) during 14 days of shelf life. S-O: *a** and *b** colour value at harvest for the optimal-harvested apple; S-L: *a** and *b** colour value at harvest for the late-harvested apple

3.2 Firmness

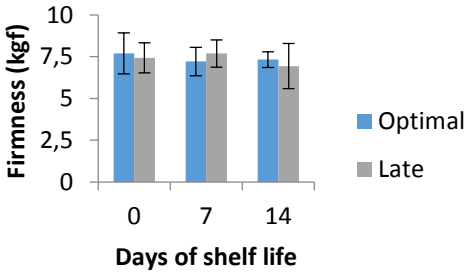

Figure 5. Firmness evolution of Jonagored apples stored in shelf life condition for 0, 7 and 14 days

It was shown that firmness decreased during shelf life. For the optimal-harvested apple, the apple become softer after 7 days of harvest. There was no significant difference observed between firmness at 7 day and that of 14 day. The late-harvested apple scored the lowest firmness at the end of shelf life. Picking time seemed to have an effect only after 14 days of shelf life in which the optimal-harvested apple were significantly firmer (7.33 kgf) than the late-harvested apple (6.94 kgf).

3.3 Soluble Solid Content

At harvest, the riper apple considerably had a higher sugar content than the younger apple. The soluble solid content of the optimal-harvested apple increased drastically along the shelf life period, whereas the riper apple maintain its soluble solid content.

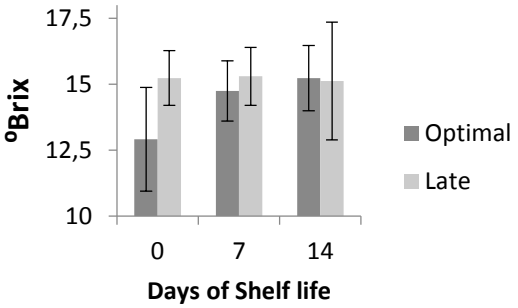

Figure 6. SSC evolution of Jonagored apples stroed in shelf life condition for 0, 7 and 14 days

3.4 Titratable Acidity

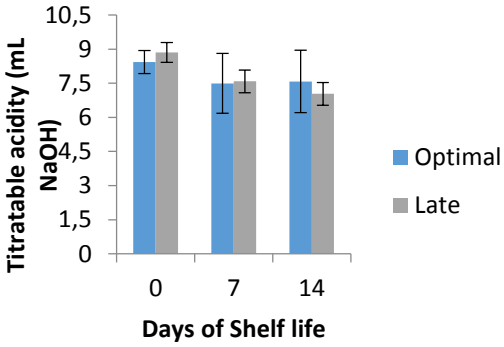

Figure 7. Acidity evolution of Jonagored apples stored in shelf life condition for 0, 7 and 14 days

Acidity evolution was also influenced by apple maturity. The more mature apple loss noticeably it acidity and scored the lowest acidity (7.03 mL NaOH) compared to the optimal-harvested (7.58 ml NaOH) at the end of shelf life (Fig.6).

3.5 Ethylene (C_2H_4)

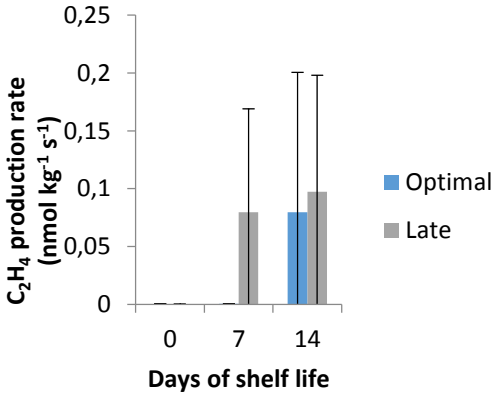

Figure 8. Ethylene production rate of Jonagored apples stored in shelf life condition for 0, 7 and 14 days

It was observed that practically no ethylene production was detected at harvest for both picking times (Fig.7). After 7 days, unlike the optimal-harvested apple, the late-harvested apples showed a bust of ethylene production (from $< 10^{-5}$ $kg^{-1}s^{-1}$ to 0.08 $kg^{-1}s^{-1}$). At the end of shelf life, either optimal-harvested apple or late-harvested apple demonstrated an increase in ethylene production. Ethylene accelerates fruit ripening and a dramatic increase in ethylene production closely related with

initiation of ripening (Saltveit, 1999). Therefore, it can be deducted that the late-harvested apple started the ripening process earlier than the optimal-pikced apple.

3.6 Respiration

3.6.1 O_2 consumption rate

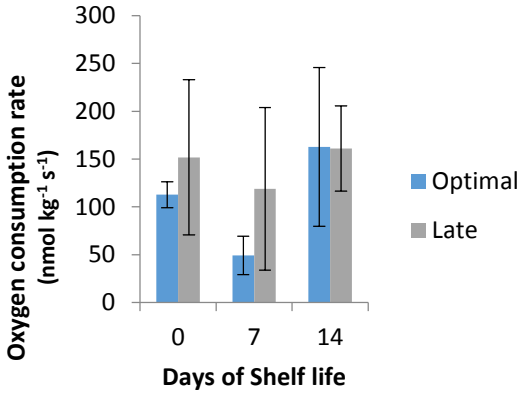

Figure 9. Oxygen consumption rate of Jonagored apples stroed in shelf life condition for 0, 7 and 14 days

It can be seen from figure.8 that at harvest and at 7 days of shelf life picking time had a considerable effect on oxygen consumption of the apple. The more mature the apple, the more the oxygen consumption of the apple. Except at 7 days of shelf life, there were a trend of increasing oxygen consumption Oxygen of the optimal-harvested apple.

3.6.2 CO_2 production rate

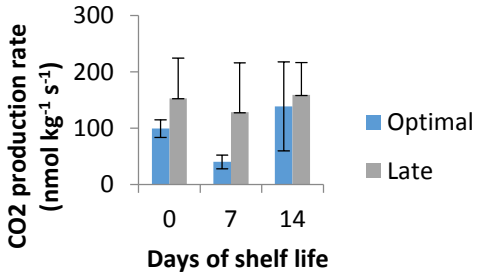

Figure 10. Carbon dioxide production rate of Jonagored apples stored in shelf life condition for 0, 7 and 14 days

At harvest, the riper apple respired higher than the younger apple (Fig.9). It produced 153 nmol $kg^{-1}s^{-1}$ CO_2 while the optimal-harvested apple emitted 99 nmol $kg^{-1}s^{-1}$ of CO_2. After 7 days, the respiration rate of the optimal-harvested apple decreased to 41 nmol $kg^{-1}s^{-1}$ of CO_2 and widen the difference with that of the late-harvested apple to three-fold differences (129 nmol $kg^{-1}s^{-1}$ of CO_2). At the the end of shelf life, the difference became smaller and statistically insignificant.

3.6.3 Respiratory quotient (RQ)

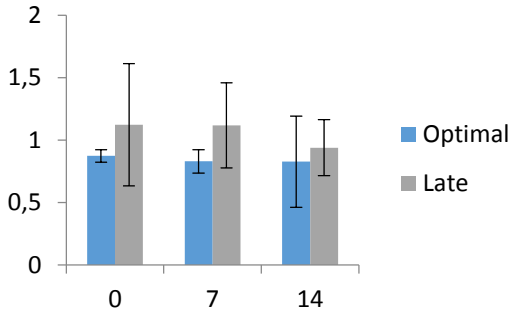

Figure 11. RQ evolution of Jonagored apples stored in shelf life condition for 0, 7 and 14 days

Later picking time of apple resulted in a higher respiratory quotient (RQ) value of apple. However the effect of shelf life was absence. The RQ values in this research varied from 0.83 to 1.12.

4. DISCUSSIONS

4.1 Colour

Colour change of apple reflects the degradation of green-pigment chlorophyll following ripening processes of fruit. During ripening, alteration in pigmentation normally involves the loss of chlorophyll and the synthesis of other pigment such as carotenoids and anthocyanins or the unmasking of these pigments which were formed earlier in the development of the fruit. A* value represents greenes (a continum from green to red) of an apple while b*value reflects contimum from blue to yellow. A more distinct change in a* colour than b* mean the apple changed it colour from green to yellow indicates the action of chlorophylase, a chlorophyll degradation enzime and synthesis of another pigments such as carotenoids (Looney & Patterson, 1967; Almela *et al.*, 1996). Figure 3 is presented below to put into perspective about significance of change in a* component and b* component in affecting colour appearance of apple. It was shown that during 14 days of shelf life a

different colour degradation pattern did occur. For the optimal-harvested apple alteration in colour mainly occurred in a* component whereas for the late-harvested apple alteration mainly took place in b* component.

4.2 Firmness

At the cellular level, firmness depends on cell size, cell wall thickness and strength, turgor pressure and the manner in which cells bind together. Dissolution of middle lamella and disassembly of cell walls facilitated by the composite action of hydrolytic enzymes in the fruit, namely, polygalacturonase, pectinesterase, B-galactosidase, pectate lyase, and cellulase is the main factor causing softening of fruit. Firmer apples undergo less bruising and loss in postharvest handling process (Konopacka & Plocharski, 2004).

4.3 Soluble Solid Content

One explanation was that a rapid starch degradation and synthesis of sugar was took place and the optimal picked apple still had more starch than the late-harvested apple (Thammawong & Arakawa, 2010). However, after 14 days sugar content of both optimal and late-harvested apple were similar implies that both apple had a same starch and sugar content.

4.4 Titratable Acidity

A number of organic acids in fruit are responsible for acid taste. The acids which are usually present in relatively large quantities are malate, citrate and tartarate. Malic acid is the predominates acid in apple. During apple fruit ripening the levels of malic acid decrease due to the action of malic enzyme. The decline in acidity is due to the cellular respiration activity in which organic acids serve as substrates that enter into the Krebs cycle to gain small amount of energy for repair processes (Taiz and Zeiger, 2002).

At harvest the late-harvested apples were more acidic than the optimal-harvested apples. This was unagreement with firmness and SSC results in wich the more mature apple scored a higher firmness and SSC. One explanation is that the rate of acid transformation were slower than the the rate of middle lamella dissolution and disassembly of cell walls as reflected by firmness as well as the rate of sugar synthesis from starch as reflected in SSC.

4.5 Ethylene

At the end of shelf life, either optimal-harvested apple or late-harvested apple demonstrated an increase in ethylene production. Ethylene accelerates fruit ripening and a dramatic increase in ethylene production closely related with initiation of ripening (Saltveit, 1999) . Therefore it can be deducted that the late-harvested apple started the ripening process earlier than the optimal-pikced apple.

4.6 Respiration

4.6.1 O_2 consumption rate

This consumptions as well as carbon dioxide production reflect respiration rate. Fruit use O_2 as a final electron acceptors in respiration processes which is essentially an enzymatic oxidation of a wide variety of compounds like starch, sugars, and organic acids by means of molecular oxygen to water and carbon dioxide (Nicolaï *et al.*, 2009). Lowering O_2 partial pressure accompanied by lifting CO_2 and cooling down the temperature around the fruit will significantly reduce respiration rate as it is applied in control atmospheres (CA) storage (Kader, 1986; Sas, 1993; Paull, 1999). From the figure also it can be observed that at the end of shelf life (14 days) both apple (optimal and late-harvested) had a similar respiration rates.

4.6.2 CO_2 production rate

CO_2 production, especially for the optimal apple, increased dramatically at 14 days of shelf life and marked the beginning of ripening process of this apple. Sudden increase of respiration rate (i.e. CO_2 production) is one sign of ripening process (Saltveit, 2003). This result is in agreement with the ethylene result wich stated that younger apple started its ripening stage later than the older apple at 14 days of shelf life.

4.6.3 Respiratory quotient (RQ)

This value range is in agreement with findings stated that the most common RQ values of whole intact fruit and vegetables range from 0.7 to 1.3 (Kader, 1987). Wider RQ range was reported for apple subjected to Dynamic controlled atmosphere (DCA) treatment (Gasser *et al.*, 2010). It was reported that during 200 days DCA chlorophyll

fluorescence storage of "Golden Delicious" apples, the RQs approximately varied from 1 to 7. The RQ is normally assumed to be equal to 1 if the metabolic substrates oxidized are carbohydrates. However, if the substrate is an acid the RQ is higher than 1 and lower if the substrate is a lipid (Kader, 1986). RQ values from this research revealed that for optimal-harvested apple, respiratory processes mainly oxidised carbohidrates ($0.83<RQ<0.87$) whereas acid is the main substrate oxidised in the respiratory processes of the late picked apple ($0.94<RQ<1.12$). This difference could be attributed to different ripening stage betwen the optimal and late picked apple.

5. CONCLUSIONS

Research results shown that both apple (late-harvest and optimal harvest) conducted quality deterioration during storage. It was also revealed that older apple (i.e. the late-harvested apple) had a higher change in almost several quality attributes. Older apple had a greater colour changes, lower firmness, higher reduction in acidity and had a higher sugar content than the younger apple. Older apple also started their ripening process earlier as expressed in their ethylene production rates and respiration rates. It was also depicted that the longer the shelf life duration the greater the alteration of the quality attributes.

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