ACCEPTED VERSION

Dynamic Controlled Atmosphere (DCA) storage of Conference pear retains background color better than normal CA storage

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Abstract

Green background color is a major quality attribute of 'Conference pear' (Pyrus communis) determining its commercial value. Proper controlled atmosphere storage can slow down yellowing of the fruit peel for several months. A storage experiment was caried out in which 'Conference' pears, harvested in September 2023 were stored in normal CA conditions of 3 kPa O_2 and 0.7 kPa CO_2 as well as dynamic atmosphere conditions. When normal CA conditions were reached the oxygen concentration was allowed to further decrease based on RQ-values measured on the whole storage volume. As long as RQ values were below 1.3 oxygen concentrations were decreased. When RQ values increased to 1.3 or above oxygen concentration was increased again. At harvest and after 4 and 8 months of storage shelf life tests were carried out at 18°C. The background color was measured using a color spectrometer as well as with an image analysis system as CIE Lab values 8 times spread over 14 days. Besides these experiments in lab conditions, trials in an industrial setting were carried out. Color was measured during shelf life after harvest and after 5 months storage. The results of the lab experiments showed that the green background color of Conference pear was better retained when stored in DCA conditions compared to classical CA storage. It was observed that in the industrial trial it was more difficult to reach lower oxygen conditions mainly because the rooms were not air tight enough. However significant lower oxygen conditions than normal CA conditions were reached resulting in better quality retention.

Keywords: CA, RQ-DCA, Quality change, Background color, Image analysis

INTRODUCTION

Next to fruit firmness is the fruit background color a major commercial quality attribute of Conference pear (*Pyrus communis* L.). Consumers, especially in Northern Europe, prefer a green background color denoting a fresh like appearance. Once harvested, fresh fruit undergo continuous degradation in quality due to various oxidative processes, such as respiration and ethylene production, occurring within the cells. Postharvest handlers attempt to limit these reactions implicated in quality breakdown by storing fresh fruit at low temperature in a controlled atmosphere with reduced O_2 concentration and elevated CO_2 concentrations, hence prolonging their storage life (Kader, 1986). During storage, the green skin background color turns yellow as the chlorophyll pigments within the skin are broken down to colorless products, and in the process the underlying yellow pigments are unmasked (Müller et al., 2007; Kräutler, 2008). Proper controlled atmosphere storage can slow down softening and yellowing of the fruit peel for several months. The O_2 concentrations however should not go below the safe margin of the anaerobic compensation point (ACP) to prevent triggering fermentation leading to the production of off-flavours and storage disorders (Franck et al., 2007). Additionally, many pear cultivars, such as Conference, are highly susceptible for high CO_2 concentrations causing internal browning, while low O_2 concentrations often result in cavities. As the ACP may vary with season, origin and picking date, a safe but likely suboptimal oxygen concentration is often maintained in regular CA storage, resulting in more quality loss than expected. Dynamic controlled atmosphere (DCA) storage searches for the lower oxygen limit, by adapting oxygen levels dynamically as a function of storage time, based on a measurement of a biological response of the stored fruit to low oxygen levels (Zanella, 2003). As oxygen levels reach lower levels metabolism slows down and heat of respiration produced by the fruit decreases resulting in less heat needed to be removed by the cooling system. This may result in energy savings for storage up to 10% (Verlinden et al., 2023).

The objective of this work was to demonstrate that RQ-DCA storage can maintain better quality fruit for longer storage times compared to the classical CA storage of 'Conference' pear. Besides setting up experiments in the lab where conditions can be strictly controlled, fruit was also stored at RQ-DCA conditions in a commercial storage plant to assess performance in non-lab conditions. Peel background color was used as the quality attribute of interest. Two color measurement methods, one based on point measurement using a spectrometer and a second one based on image analysis of photographs taken in a controlled setup were compared.

MATERIALS & METHODS

Pear fruit storage and shelf life assessment

The 'Conference' pear fruit were harvested on September 5, 2023 at optimal commercial ripeness in Bierbeek, Belgium and stored at -0.6 °C in regular air for three weeks. After this cooling period, the pears were transferred into air-tight polypropene fruit storage containers of about 300 L. Within the containers, the atmosphere was controlled. In the CA treatment, the atmosphere was controlled at 3 kPa oxygen and 0.7 kPa carbon dioxide. For the RQ-DCA treatment, the carbon dioxide concentration was maintained at 0.7 kPa, while the oxygen concentration was dynamically adjusted (range between 3 and 0.3 kPa) according to automated RQ measurements on the whole fruit storage container (Bessemans et al., 2016). When normal CA conditions were reached the oxygen concentration was allowed to further decrease based on RQ-values measured on the whole storage volume. As long as RQ values were below 1.3 oxygen concentrations were decreased. When RQ values increased to 1.3 or above oxygen concentration was increased again.

Pear samples from the same harvest batch were also stored in a commercial CA-room together with the pears of the same orchard. In the commercial room pears were also kept in regular air for 3 weeks before slowly establishing CA conditions of 3 kPa oxygen and 0.7 kPa carbon dioxide. At 95 days after harvest RQ-DCA control was started. The realised gas conditions can be found in Figure 1.

Fruit quality of fruit stored in lab containers was assessed at harvest and after 4 and 8 months of storage during a shelf life period in regular air (RA) at 18°C. measurements were carried out a few hours after taking the fruit out storage and 7 additional measurements spread over a period of 12 days.

Fruit quality measurements

Assessment of peel background colour was carried out at harvest and after 4 and 8 months of storage. At harvest 30 fruits were measured for each assessment during shelf life. After storage 15 fruit were measured for each storage condition at each assessment in shelf life.

Colour measurement

The colour of the fruit was measured using a CM-2600d spectrophotometer (Konica Minolta Sensing Ltd., Singapore). For each fruit, the skin background colour is measured five times on green parts of the fruit as CIE Lab values. The values were averaged to obtain the mean value for that fruit.

Pictures of pear fruit were taken using a digital camera in small cabinet setup with standard LED lighting and fixed distances. Using image analysis the pear background color of the pear fruit was segmented from the rest of the pictures. The RGB values of the pixels segmented as pear background color were converted into CIE Lab values and averaged per pear.

Statistical analysis

To denote statistical differences after 4 and 8 months of storage a two-way anova was caried out with days in shelf life and storage condition (CA or DCA) as factors. A full factorial design was applied using JMP®, Version 17. SAS Institute Inc., Cary, NC, 1989–2023. To judge differences between storage conditions at specific shelf life days Tukey's HDS multi comparison test was applied.

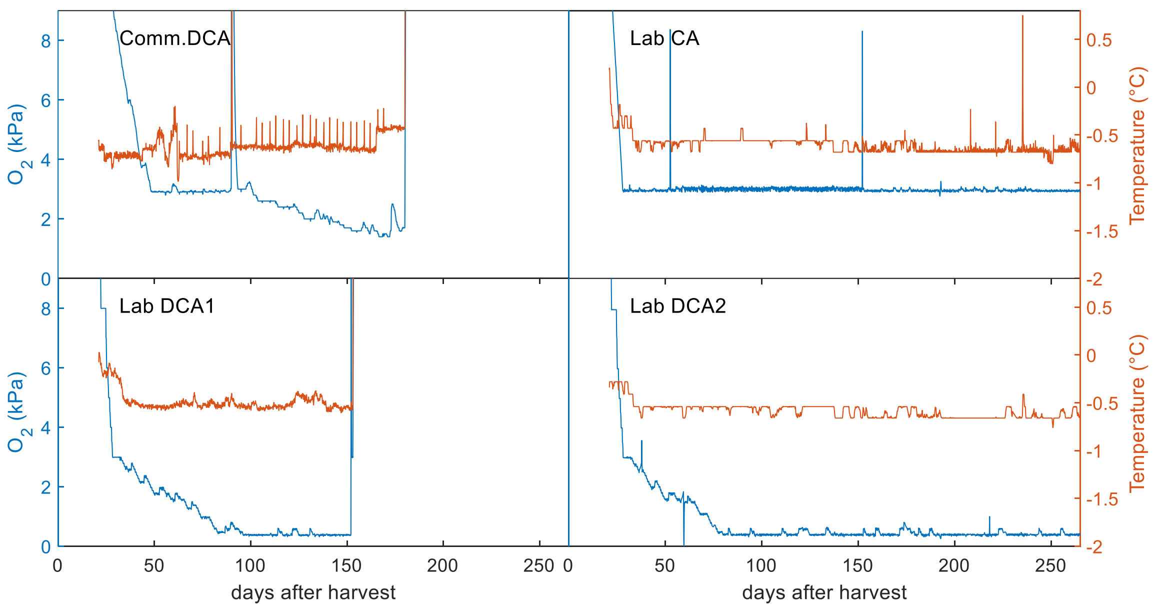

Figure 1. Realized storage conditions in the commercial storage room (top left), the lab storage container with constant CA condition, 3 kPa O_2 and 0.7 kPa CO_2 (top right), and the two DCA containers with varying O2 conditions (bottom). Temperature was kept around -0.6°C.

RESULTS AND DISCUSSION

Color change during CA and DCA storage

After harvest 'Conference' pears are first cooled down in kept in RA for 3 weeks. This is a standard protocol that will prevent development of core browning and cavity formation later in storage. After these first 3 weeks a first assessment of the background color was made and CA or DCA storage protocols started. The realised O_2 and temperature conditions can be seen in Figure 1. In the lab pears were stored up to 268 days after harvest (8 months) in CA and in RQ-DCA conditions. The storage in commercial RQ-DCA conditions lasted only 182 days (5 months) as the owner of the fruit decided to open the room and commercialize the fruit. While in lab conditions it was fairly easy to start the DCA protocol after reaching the classical CA conditions (3 kPa O_2 and 0.7 kPa CO_2), it took some convincing and unexpected practical problems before this could be started in the commercial room. Eventually the RQ-DCA protocol was started around day 95 after harvest. As can be seen in Figure 1 the O_2 concentration gradually decreased until levels of about 1.3 kPa while in lab conditions the lower limit set by the system of 0.3 kPa was reached at about day 80 and was maintained for the rest of the storage period. The raison why the commercial room did not reach the same low O_2 values as the lab DCA containers were because of leakiness of the room. The RQ measurements in the commercial room were still around 1 denoting aerobic respiration conditions but the lowered respiration of the fruit was not able to compensate the increase in O_2 concentration because of leakage. At the end of the storage background color was measured again as can be seen in Figure 2. The left pane shows the a* values 21 days after harvest and at the end of storage of the 3 storage conditions. Lower negative a* values correspond to greener color while less negative and positive values correspond to more yellow colors. The Lab DCA storage was able to maintain the same values as at harvest while the CA storage showed yellowing. The commercial DCA showed values in between as expected because a large part of the storage was actually constant CA. In the right pane corresponding Hue values are shown. A higher Hue value correspond to a more green color while a low Hue value is more yellow. The same trends were seen here. CA storage becomes the most yellow after storage followed by the commercial DCA and the Lab DCA was able to maintain similar values as at harvest.

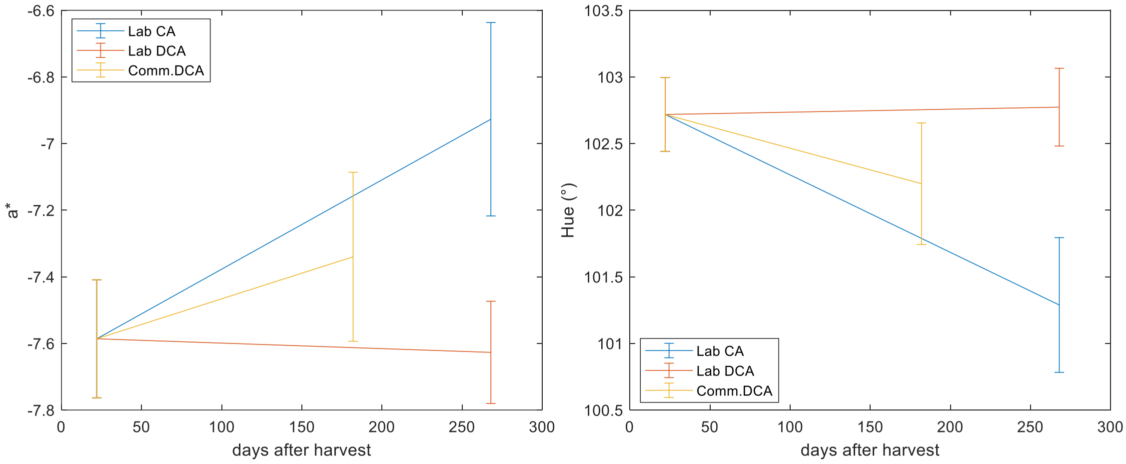

Figure 2. Color change of background color during storage in constant CA condition, 3 kPa O_2 and 0.7 kPa CO_2 (blue), DCA in the lab (red) and DCA in commercial environment. Color measured with a Minolta spectrometer expressed as a* (left) and Hue values (right). Bars denote standard errors.

Color change during shelf life after storage

After 4 and 8 months of storage in the lab containers samples were taken out and put into shelf life conditions in RA at 18°C. Peel background color was measured 8 times during 12 days both with a color spectrometer and with an image analysis system. Results are shown in Figure 3. Unfortunately, measurement of color spectrometer during the first week of shelf life after 4 months of storage were lost due to technical problems. As was to be expected color change during shelf life was much higher than the change during the whole 8 months of (D)CA storage. As can be seen in Figure 2 the color change during 8 months in normal CA, the least performing storage conditions, was less than 1 a* unit and about 1.5° for Hue while during 12 days of shelf life the color changed 5 a* units and 15° for Hue. These changes corresponded with the peel background color going from fresh green to ripe yellow. As the change very significant because of the shelf time duration the storage condition either normal CA or RQ-DCA showed no significant effect after 4 months of storage (Figure 3 left panes). After 8 months of storage significant effect of storage condition were detected (Figure 3 right panes). Hue values of DCA stored pears (dashed lines) started with higher values, meaning more green color, than CA stored pears and consistently kept higher values till 6 days (day 274 after harvest) in shelf life. Similarly, a* values of DCA stored pears were consistently lower, and so more green, than CA stored pears.

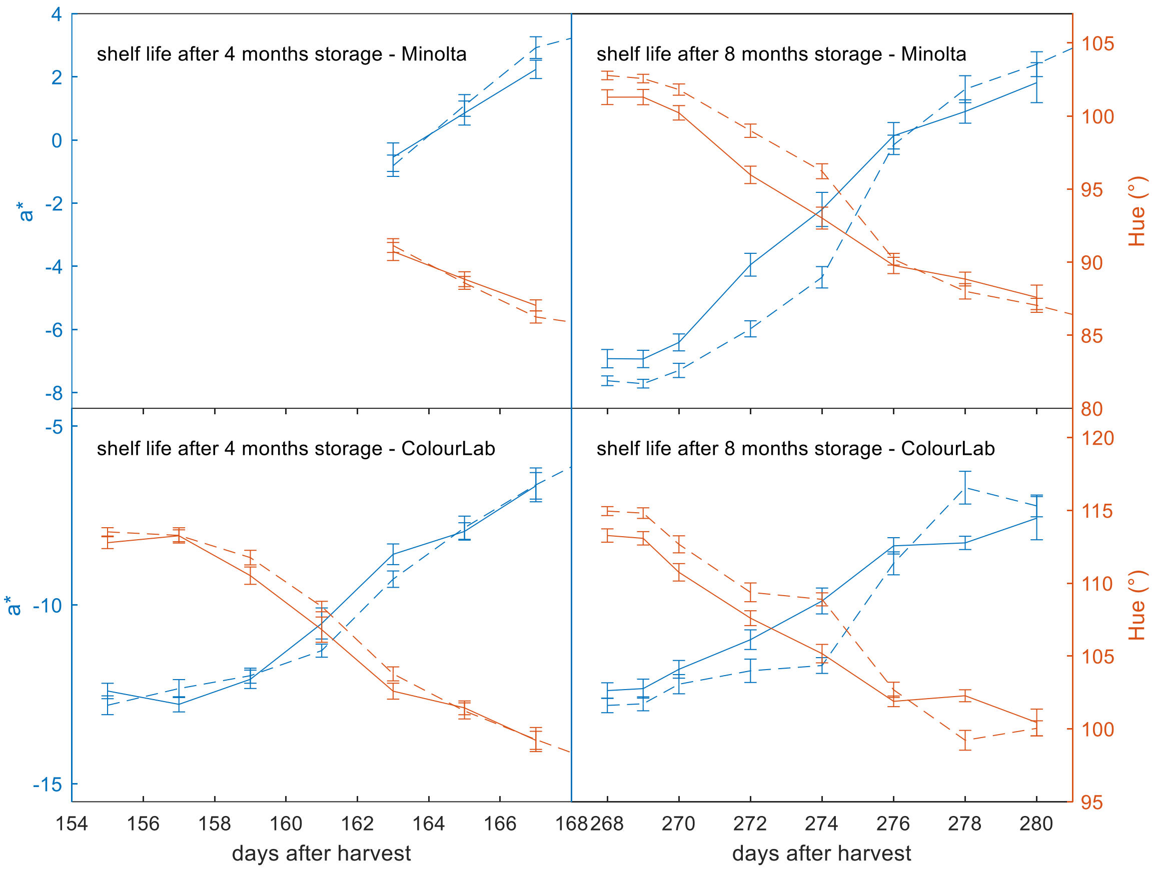

Figure 3. Color change during shelf life in RA at 18°C of background color after 4 (left column) and 8 months (right column) storage in constant CA condition, 3 kPa O_2 and 0.7 kPa CO_2 (full lines) and DCA (dashed lined). The top row contains the measurements carried out with a Minolta spectrometer and the bottom row shows the results measured with the image analysis system. Bars denote standard errors.

Figure 4 shows the photographs taken with the image analysis system right after 8 months storage (top row) and on day 6 in shelf life (bottom row). At the start of shelf life it was not obvious to see differences by eye of the peel background color between the two storage conditions CA and DCA but after 6 days differences were obvious as was confirmed by a multi comparison test for both the a* and Hue values measured with both methods.

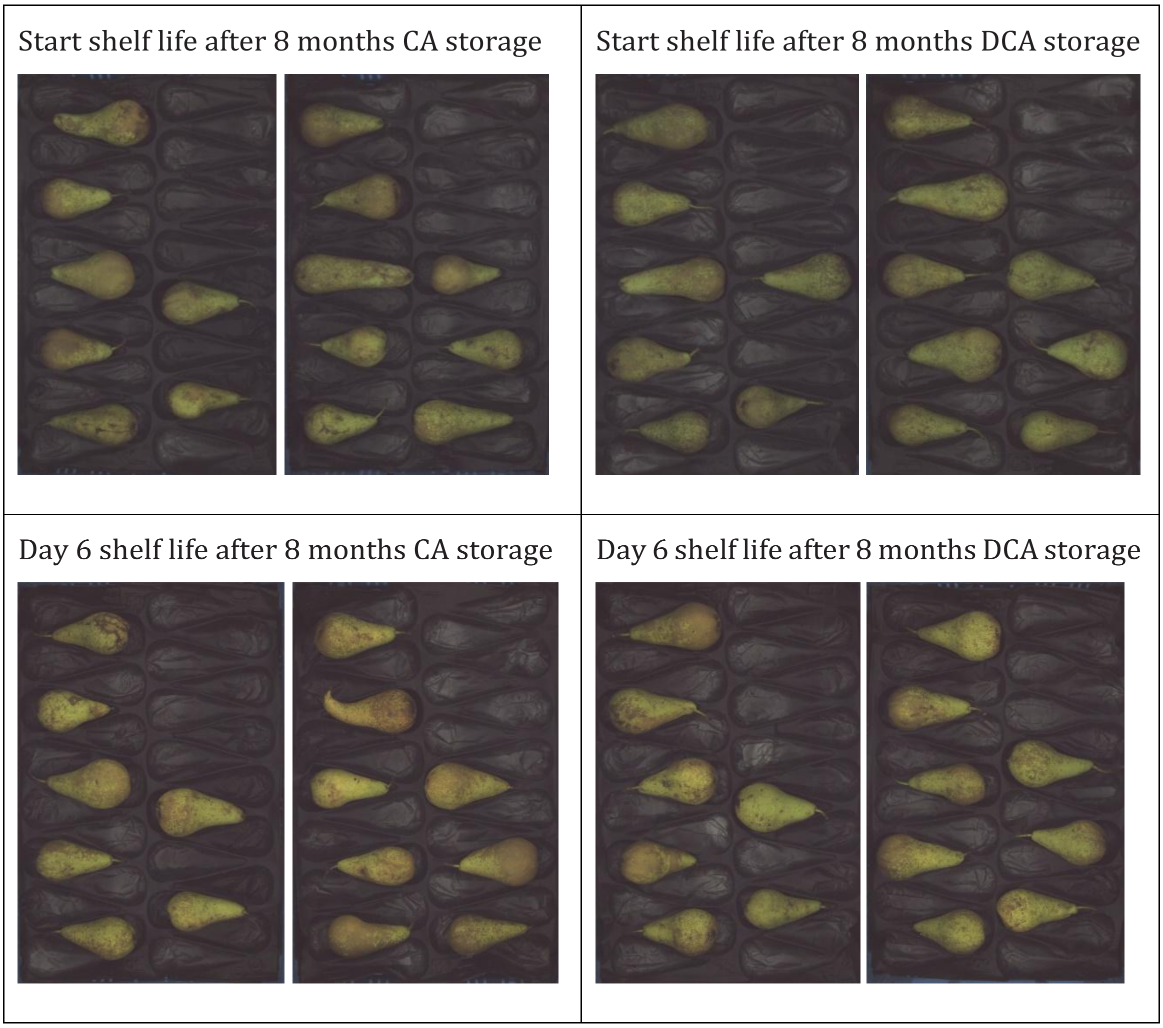

Figure 4. Photographs of 'Conference' pears stored for 8 months in CA and DCA conditions right after storage and after 6 days of shelf life in RA at 18°C.

Comparing color measurement using spectrometry and image analysis

Measuring color of food objectively is not straightforward (MacDougall, 2002). The perception of color by the eye not only depends on the 'objective' color of the pigments but also of the environmental light, the angle with which we look to the coloured surface and physical properties of that surface that determine how the light will be reflected. To measure color of fruit objectively it will be at least needed to standardise the light used and the angle of observation. This was the case in both color measurement methods used but not in the same way which is part of the explanation why the two method give different values for the same fruit measured. As can be seen in Figure 3 the spectrometer measurement gives lower values for Hue angel, about 25 degrees, and higher values for a°, about 10 units. As can be judged from the error bars the variability and noise on the two measurement methods is about the same. Both methods will be able to demonstrate the same differences however the two method show a significant offset in color values that is large compared to difference between the two storage conditions one wants to show that were in the order of 1 a* unit and 5° Hue. This might be further explained by the particular peel features of 'Conference' pear. Pear have rough brown regions on their skin which are sometimes difficult to avoid using the spectrometer measurement method as it measures spots of a few millimetre in diameter. The image analysis system on the other hand can easily exclude the brownish pixels from the green peel.

CONCLUSIONS

Two color measurement techniques, one besed on spectrometer measurements and another on image analysis were used to asses the color of ‘Conference’ pears after storage and subsequent shelf life. Both methods were able to generate color data of the same statistical quality. However the image analysis method was believed to result in color values matching better the color of the unrough regions of the pear skin while those of the spectroscopic method was contaminated with the color of the rough regions typical for ‘Conference’ pear.

The results of the lab experiments showed that the green background color of Conference pear was better retained when stored in RQ-DCA conditions compared to classical CA storage. It was observed that in the industrial trial it was more difficult to reach lower oxygen conditions mainly because the rooms were not air tight enough. However significant lower oxygen conditions than normal CA conditions were reached resulting in better quality retention.

Adoption of DCA technology in industry should be encouraged as better quality retention would lead to less fruit losses and lower respiration heat production to lower energy consumption during storage. Both beneficial for countering climate change and realizing a more sustainable world.

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