Chlorophyll Fluorescence and Gas Exchanges in 'Abbé Fétel' and 'Conference' Pears Stored in Atmosphere Dynamically Controlled with the Aid of Fluorescence Sensors

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Abstract

A new technology for monitoring the physiological status of fruit during storage (HarvestWatch™ system with FIRM™ sensors, Satlantic, Canada) was used to detect anaerobic stress in pears by the increase in fluorescence response (Fα). Two pear cultivars were studied: 'Conference', a long-term storage cultivar, and 'Abbé Fétel', which cannot be stored longer than 4 months in air. The fruit were stored in air at -0.5°C after harvest until 18 November 2002, then in 4 gastight containers (2 per cultivar). In each container there was a fluorescence sensor in a box with 6–7 fruits. One container per cultivar was kept with a standard CA (2 kPa O_2; 0.7 kPa CO_2); in the other, after 3 weeks with standard CA, the oxygen concentration was decreased. On 10 February ten fruits per container were sampled, and gas exchange was measured at -0.5°C on single fruit in known gas mixtures (100 kPa N_2, O_2 at 0.1, 0.5, 2 and 21 kPa, with 0 and 5 kPa CO_2). 'Abbé Fétel' fruit had higher gas exchange rates and were more sensitive to low O_2, experiencing and increase in fluorescence response at higher O_2 level than 'Conference' fruits. The sensitivity to low oxygen levels was confirmed by respiratory quotient, which increased at O_2 levels similar to those which stimulated the change in fluorescence response. Therefore it seems that Fα measures a response to the low O_2 stress which induces anaerobic respiration. The fluorescence monitoring system may have potential to detect physiological limits for aerobic respiration. A CA system with excellent tightness, analytical accuracy and control is needed to implement the HarvestWatch system. However, even under optimal atmospheric control, the small number of fruit that can be monitored may present challenges to successful implementation if sample fruit are not representative of the bulk of fruit in storage.

INTRODUCTION

Chlorophyll fluorescence can be a marker of low oxygen or high CO_2 stress in apples (DeEll et al., 1995). In fact fluorescence parameters F_0 and F_v/F_m increase and decrease respectively with time during low oxygen stress (Mir et al., 1997; Prange et al., 1997) and ethanol, a product of anaerobic respiration, increases (Prange et al., 1997). The same occurs with decreasing oxygen concentration (Prange, 2002).

A new technology for monitoring the physiological status of fruit during storage (HarvestWatch™ system with FIRM™ sensors, Satlantic, Canada) was introduced following the studies of Prange (2002) about the effects of oxygen concentration on chlorophyll fluorescence in fruits: chlorophyll fluorescence increased when oxygen concentration decreased below a physiological limit. The Fluorescence Interactive Response Monitor (FIRM™) uses low power light source to stimulate photosystem inside a small sample of the produce. The fluorescence response from the fruit is detected and fed back to an analytical software tool which produces a theoretical estimate of F_0 at zero irradiance, called Fα (Prange et al., 2003). The absolute value of Fα is then normalized to percent of the initial value, to compensate for differences in fruit size or distance from the sensor.

A trial was carried out with the aim of studying the application of this method to

detect anaerobic stress in pears. Unfortunately the sensors arrived at the laboratory about two months after fruit harvest, so it was not possible to use them for the whole storage season. Two pear cultivars were studied. 'Conference' is well known as a long term storage cultivar, although in some conditions it can be affected by brown heart in CA. 'Abbé Fétel' is appreciated for its quality characteristics but cannot be stored longer than 4 months in air, while in CA it is often sensitive to a senescent scald disorder.

MATERIALS AND METHODS

'Conference' and 'Abbé Fétel' pears were picked on 21 August and 4 September 2002 respectively, in Modena province. On the day of harvest, a sample of 20 fruit per cultivar was analysed for fruit mass, hue of skin colour (Minolta Chromameter), flesh firmness (8 mm diameter plunger mounted on an Instron UTM at crosshead speed of 200 mm/min), starch with iodine solution assessed on a 10-point scale (1=no starch hydrolysis; 10: no starch), soluble solids in fruit juice with a refractometer (Atago) and acidity titrated with NaOH 0.1N. The fruit were stored in air at -0.5°C after harvest until 18 November 2002, and then were moved to gastight containers. Four containers were used, two for each cultivar; one box of fruits containing about 50 fruits and a fluorescence sensor in a small box with 6–7 fruits was stored in each container. Sensors were activated from 4 December. One container per cultivar was kept with a standard CA (2 kPa O_2; 0.7 kPa CO_2). The other one (dynamically-controlled atmosphere by fluorescence, FCA), after 3 weeks with standard CA, from 9 December was left without oxygen supplementation, with oxygen decreasing due to respiration; when an increase of fluorescence would signal a too low O_2 level, then O_2 was set to the level immediately above the stress level, keeping CO_2 at 0.1 kPa. On 10 February ten fruits per container were sampled, and gas exchange was measured. Measurements of gas exchange rates were carried out at -0.5°C on single fruit using gastight glass jars. Gas exchange rates were measured statically after a 4-day equilibration time at -0.5°C in known gas mixtures, and analysing the change in gas composition after 24 hours using a MicroGC according to de Wild and Peppelenbos (2001). Gas mixtures used were: 100 kPa N_2, O_2 at 0.1, 0.5, 2 and 21 kPa, each with low (0 or 0.7 kPa) or high (5 kPa) CO_2 concentration. O_2 uptake and CO_2 production rates were expressed as $nmol \cdot kg^{-1} \cdot s^{-1}$ in standard conditions, considering the volume of the jar, the volume and the mass of the fruit, correcting for actual values of temperature in the cold room and the pressure in the jar at time=0 and time=24 h. Respiration quotient (RQ) was computed as the ratio between CO_2 production and O_2 uptake rates.

RESULTS AND DISCUSSION

The quality indices measured at harvest are reported in Table 1. The firmness values correspond to the normal commercial harvest maturity suggested for each cultivar.

In FCA treatments, after 9 days without oxygen supply, O_2 concentration decreased from 2 to 0.8 kPa (Fig. 1). When O_2 concentration further decreased to 0.6 kPa, 'Abbé Fétel' pears showed a sharp increase in Fα. 'Conference' pears showed a similar increase only when O_2 decreased below 0.4 kPa (Fig. 1). Therefore O_2 concentration was set at 0.7 kPa for 'Abbé Fétel' and 0.5 kPa for 'Conference'. In CA treatments there was no sharp variation in Fα, only a slow but steady increase in 'Abbé Fétel', while in 'Conference' Fα was constant during storage (Fig. 2). The sensors were sensitive to external light, as it is shown by the peaks in Figure 2, which are due to the light switched on in the cold room.

Gas exchange results showed that 'Abbé Fétel' fruit had a higher rate of CO_2 production, also in anaerobic conditions, than 'Conference' fruit (Fig. 3). The shorter storability of 'Abbé Fétel' pears could be related to the higher respiration rates. Fruit stored in CA showed higher gas exchange rates than those in FCA (Fig. 3). The lower respiration rates of fruit previously stored in FCA could mean an adaptation of fruit metabolism to low oxygen levels. At high O_2 concentrations the exchange rates of O_2 and CO_2 were about the same and respiratory quotient (RQ) was near 1, denoting that

respiration was mainly aerobic (Fig. 4). With decreasing oxygen a significant increase of RQ was found with O_2 ≤0.5 kPa in both cultivars stored in CA and in 'Abbé Fétel' stored in FCA, showing an increase of anaerobic respiration, while in 'Conference' stored in FCA the respiration was still aerobic (RQ = 1) even with 0.5 kPa O_2 and became anaerobic at 0.1 kPa O_2. Aerobic and anaerobic respirations are not mutually exclusive, but an increase in anaerobic respiration indicates that O_2 level is not sufficient to sustain fruit energy demand. The results of respiration measurements are in agreement with the fluorescence response, which showed a stress at O_2 concentration below 0.6 kPa in 'Abbé Fétel' and below 0.4 kPa in 'Conference'.

After the respiration measurement, the CA system incurred in a series of problems which altered the atmospheres set. The quality of fruit after storage therefore cannot be ascribed purely to the designed atmosphere treatments. 'Abbé Fétel' fruit were more affected by decay perhaps because, being large, suffered more mechanical injury from contact with the fluorescence sensor box in the treatment chamber (Fig. 5). Decay was higher in FCA than in CA. Senescent scald was highest in 'Abbé Fétel' in FCA, and superficial scald in 'Conference' in CA.

CONCLUSIONS

'Abbé Fétel' fruit had higher gas exchange rates and were more sensitive to low O_2, increasing their fluorescence response at higher O_2 level than 'Conference' fruits. The sensitivity to low oxygen levels was confirmed by respiratory quotient, which increased at O_2 levels (0.6 and 0.4 kPa for 'Abbé Fétel' and 'Conference' respectively) similar to those which stimulated the change in fluorescence response. Therefore it seems that Fα measures a response to the low O_2 stress which induces anaerobic respiration.

The fluorescence monitoring system may have potential to detect physiological limits for aerobic respiration. The response is immediate, so that measures can be taken before the damage becomes irreversible. Such a system, which aims at controlling the oxygen concentration at the lowest level compatible with normal, aerobic respiration of fruit, requires an excellent CA system as regards gas tightness, analysis and control. Especially in the case of pears, very efficient CO_2 scrubbers are required, in order to maintain very low levels of CO_2.

A problem that can be envisaged in large commercial store rooms is that of the small fruit sample. One fluorescence sensor can only detect the response of 6 fruits, so the fruit samples for fluorescence monitoring must be carefully selected: the choice of the fruit should be oriented towards most sensitive fruits, while the number of sensors per room has to be determined on the basis of the possible variability of conditions in the room.

Literature Cited

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Tables

Table 1. Characteristics of 'Conference' and 'Abbe Fetel' pears at harvest.

Cultivar	Date of harvest	Mass (g)	Hue (radians)	Firmness (N)	Starch (1-10)	Soluble solids (°Brix)	Acidity (meq/ 100 g)
'Conference'	21 Aug 2002	175	2.00	59	6.6	12	2.1
'Abbé Fétel'	4 Sep 2002	343	1.92	48	6.4	13	3.8

Figures

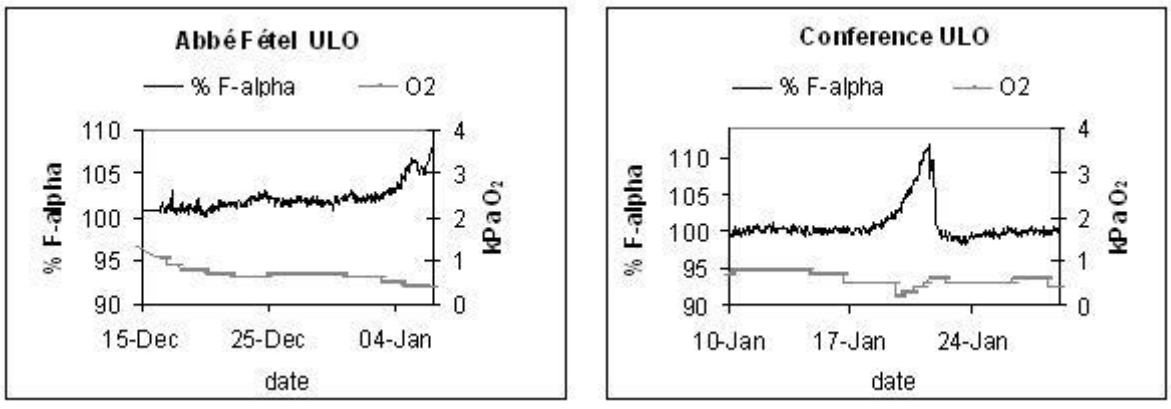

Fig. 1. Oxygen partial pressure and corresponding response of F-alpha for 'Abbé Fétel' (A) and 'Conference' (B) pears during storage in dynamically-controlled atmosphere by fluorescence (FCA) at -0.5°C.

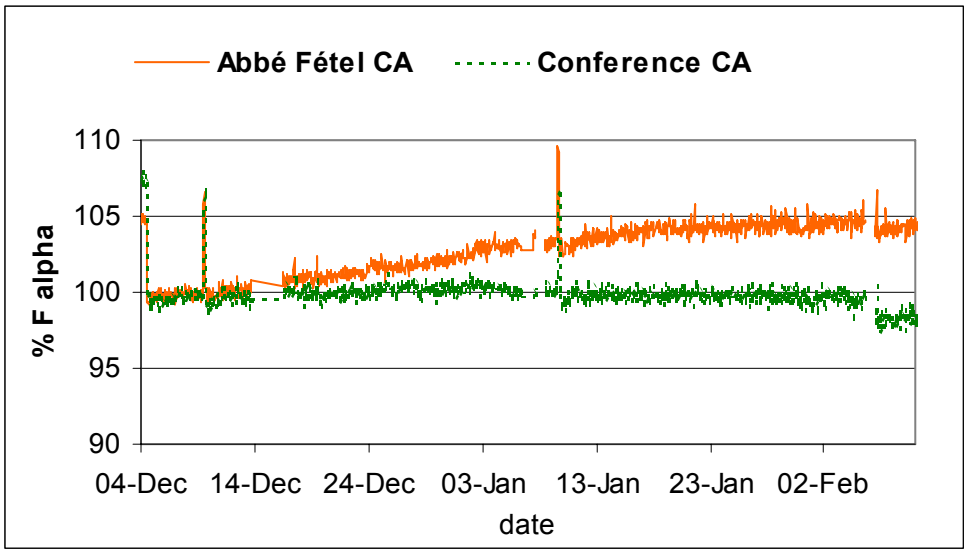

Fig. 2. Fluorescence response of 'Abbé Fétel' and 'Conference' pears during storage in CA with 2 kPa O_2 and 0.7 kPa CO_2 at -0.5°C for 2 months. Peaks are due to external light switched on.

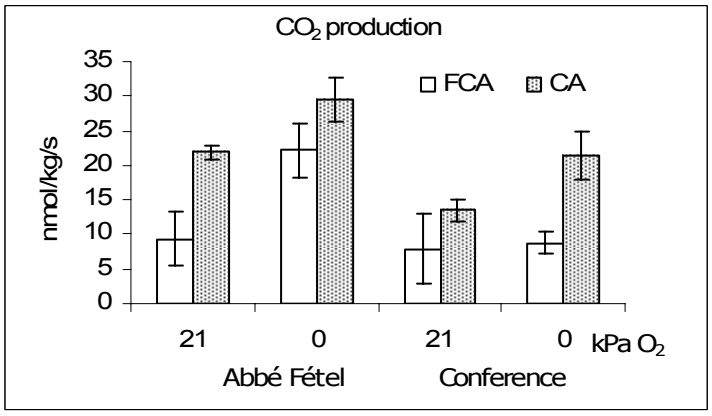

Fig. 3. Means and standard deviations of CO_2 production of 'Conference' and 'Abbé Fétel' pear fruits (n=2) in 21 and 0 kPa O_2 after storage in FCA or CA at -0.5°C for 2 months.

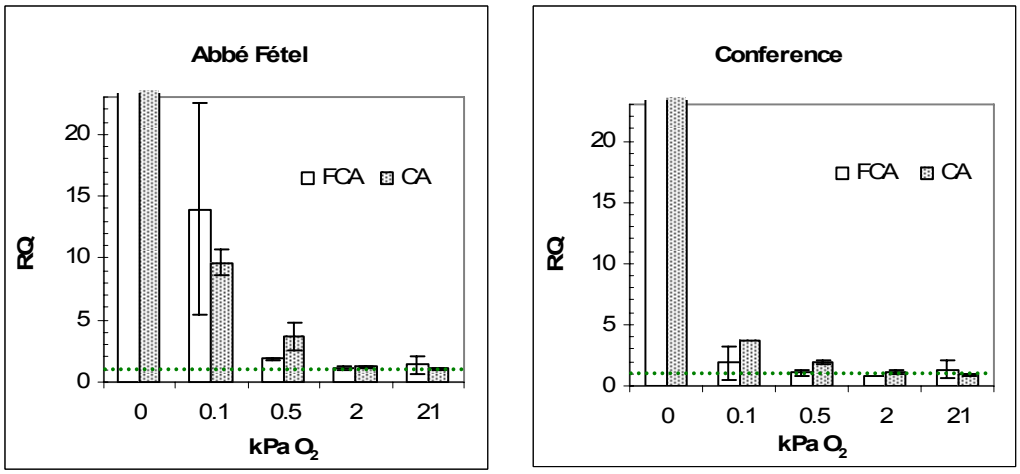

Fig. 4. Respiratory quotient (mean and standard deviation, n=2) of 'Abbé Fétel' and 'Conference' pears at different pO_2 after storage in FCA or CA at -0.5°C for 2 months. The dotted lines indicate RQ = 1.

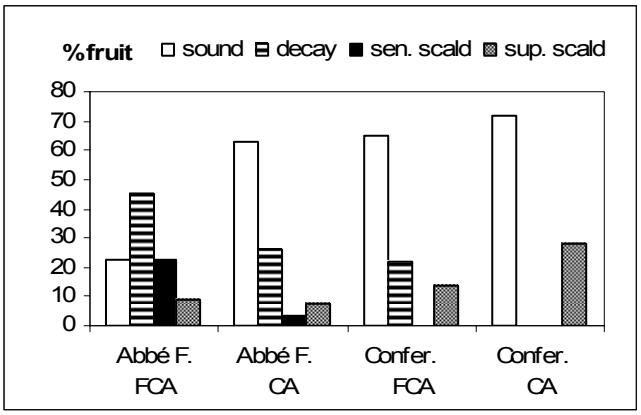

Fig. 5. Percent fruit sound, affected by rot, senescent scald and superficial scald after storage in FCA or CA at -0.5°C for 2 months (n=32).