Production Practices and Quality Assessment of Food Crops

Volume 4

Postharvest Treatment and Technology

Edited by
Ramdane Dris and S. Mohan Jain

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PREFACE

We can not talk about commodity production without building up all the operations after harvest. It is possible to market the products just after harvest, but it is only possible in small quantities. Postharvest handling is the ultimate stage in the process of producing quality fresh fruits and vegetables, getting these unique packages of water (fresh commodities) to the supper table. Fresh fruits and vegetables are succeptible to a number of postharvest disease and disorders and the postharvest operations are predominately aimed at maintaining harvest quality. Every step in the handling chain can influence the extent of disease and quality of the stored product. From planting to consumption, there are many opportunities for bacteria, viruses, and parasites to contaminate produce or nutrient deficiency level causing physiological disorders. Most of the storage rots are diseases that have originated in the field and have carried over onto commodities after harvest. Physiological disorders also arise from poor handling between harvest, storage and marketing. Treatments have a direct effect on inactivating or outright killing germinating spores, thus minimising rots. Prestorage treatment appears to be a promising method of postharvest control of decay. Pre-or-postharvest treatments of commodities are considered as potentiel alternatives for reducing the incidence of diseases, disorders, desinfestation of quarantine pests and for preserving food quality. Postharvest treatments lead to an alteration of gene expression and fruit ripening can sometimes be either delayed or disrupted. the tolerance to high and low postharvest temperatures may be influenced by preharvest high temperatures of the crop. Cell wall degrading enzymes and ethylene production are frequently the most disrupted and are sometimes not produced or their appearance is delayed following heating.

Eleven chapters are included in this book, which are: Application of Sensitive Trace Gas Detectors in Post-harvest Research; Radio Frequency Post-Harvest Quarantine and Phytosanitary Treatments to Control Insect Pest in Fruits and Nuts; Calcium, Polyamine and Gibberellin Treatments to Improve Postharvest Fruit Quality; Ionization of Fruits and Vegetables for Fresh Consumption – *Effect on detoxication Enzymatic Systems and the Lipid Fraction*; Treatments and Techniques to Minimise The Postharvest Losses of Perishable Food Crops; Strategies for the Regulation of Postharvest Fruit Softening by Changing Cell Wall Enzyme Activity; Posthavest Treatment of Fruits; Postharvest Treatments of Satsuma mandarin (*Citrus unshiu* Marc.) For the Improvement of Storage Life and Quality; Sprouting Radioinhibition: A Method to Extend the storage of Edible Garlic Bulbs; Postharvest Processing of Fruits and vegetables by Ionizing Radiation; Desinfestation of Fresh Horticultural commodities by Using Hot Forced Air With Controlled Atmospheres.

This book covers various aspects of postharvest handling quality and the use of different treatments to reduce the incidence of diseases or physiological disorders affecting the quality maintenance of the food crops. Also described is the production, packaging, cooling, transportation, and marketing costs of crops. It is obvious that marketing positions are uncertain without a complex postharvest

network. The challenge facing industries is to produce food of good quality with few chemical inputs as public concern increases over food safety, environmental issues and chemical resistance.

The editors wish to express their sincere gratitude to all authors for their valuable contributions. We are grateful to Kluwer Academic Publishers for giving us an opportunity to compile this book.

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CONTENTS

APPLICATION OF SENSITIVE TRACE GAS DETECTORS IN POST-HARVEST RESEARCH

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1. INTRODUCTION: RELEVANCE OF TRACE GAS MONITORINGTO POST-HARVEST RESEARCH

In human diet fruit are highly appreciated and form an important source of various essential elements like vitamins and minerals. Furthermore, most fruits only contain low amounts of fat, which is of great importance in a modern diet (Wilson et al., 1979). Extending the shelf life of fresh fruits to prolong its availability over the season and to diversify the diet requires storage under controlled conditions, i.e. at low temperatures often in combination with a modified gas atmosphere. In ancient times a modified gas atmosphere was achieved by applying ingenious techniques such as the application of fresh leaves and grass in sealed clay pots used for fruit transport. Addition of the leaves and grass generated an atmosphere containing low O_2 and high CO_2 concentrations, thereby slowing down respiration and thus ripening (Peppelenbos, 1996 and references therein).

In modern fruit storage facilities, the gas atmosphere is often actively altered by applying nitrogen generators or carbon dioxide scrubbers (Knee, 1991). In addition, other measures can be taken such as controlling the ethylene level in the storage room using ethylene converters (Reid, 1992). Ethylene is a gaseous plant hormone inducing ripening in some fruit at low gas concentrations (Abeles et al., 1992; Salveit, 1999). Typical gas conditions applied during storage of fruit are 1–10% oxygen and 0–10% carbon dioxide (Beaudry, 1999). In order to suppress the crops' respiration further application of even lower oxygen levels is currently exploited (Lau et al., 1998). Under such low oxygen levels the crop can start to ferment thereby producing a number of fermentative compounds, such as acetaldehyde and ethanol (Yearsley et al., 1996). Fermentation can lead to the formation of off-flavours or odours (Fidler, 1951; Mattheis et al., 1991), whereby acetaldehyde acts as a strong cell toxin (Perata et al., 1991; Tadege et al., 1999). Monitoring

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the volatile concentrations of acetaldehyde and ethanol can thus reveal whether or not appropriate storage conditions are applied, i.e. if oxygen conditions are not too low (Schouten, 1995). Note that acetaldehyde and in lesser extent ethanol can also have beneficial effects on the produce as short-term anaerobic treatments on harvested fruit improved their aroma and quality (Pesis, 1995). Moreover, external application of acetaldehyde inhibits ripening in a great number of fruits (Beaulieu et al., 1997) while ethanol can prevent scald in apples (Scott et al., 1995).

Other important volatiles released by horticultural crops include ethylene, a marker for ripening stage in certain fruits (Burg et al., 1962); nitric oxide, hypothesised to be a natural plant growth regulator (Leshem et al., 1998); and ethane, an indicator for damage such as chilling injury (Kuo et al., 1989). Monitoring release of volatile molecules can thus provide insight in biochemical and physiological processes of the crop in a non-invasive way. Volatiles may serve as marker for disorders or sub-optimal storage conditions. However, it must be stressed that these gases are often released in tiny amounts and hence long accumulation periods are needed to obtain concentrations that can be detected using standard techniques such as gas chromatography. During accumulation the levels of many compounds in- and outside the fruit change thereby possibly altering its metabolism (Monk et al., 1987). Gas detectors based on the photoacoustic (PA) effect are much more sensitive and use of PA-detectors makes the accumulation process superfluous (Harren et al., 1997). Over the past years this kind of detectors have been applied to study a wide range of biochemical and physiological processes in plants, fruits and seeds. These include dehydration response of germinating radicles (Leprince et al., 2000), pollination (De Martinis et al., 2002) and wilting of flowers as studied by monitoring the release of ethylene (Woltering et al., 1988), bell peppers under anaerobic and post-anaerobic conditions (Zuckermann et al., 1997), and simultaneous detection of five gases in a fruit storage room using a mobile photoacoustic detector (Nägele et al., 2000). Due to their fast time-response PA detectors are optimally suited to study on-line processes in which gas emissions are changing rapidly. In this study such detectors are applied to study the dynamics of trace gas emissions by fruits.

The first application deals with release of ethylene by a variety of tropical fruits grown in Indonesia. Interest in most (sub-) tropical fruits has been scarce until recently when their economical potential and nutritional value was realised (Kader, 1993; Burden, 1997). The successful introduction to the Western market of avocadoes, mangoes, papayas and fresh pineapples is now followed by a whole range of 'new' fruits. A survey shows the ethylene emissions of several tropical fruits, some of which are still unknown by the majority of the Western consumers. In the second application trace gas emissions by avocados are studied during exposure of the fruit to short anaerobic or low-oxygen treatments. Especially the emission of the very volatile molecule acetaldehyde is of interest since it provides an early indication for fermentation as compared to the less volatile ethanol (Zuckermann et al., 1997; Oomens et al., 1998). Closely related to this topic is the third application, which shows the inhibitory effects of exogenously applied acetaldehyde or short anaerobic shocks on the ethylene emission by apples.

Note that in some experiments compounds are released at relatively high rates

however the fast time response of the applied detectors – a unique feature of the detectors – is needed to follow the quickly changing release rates.

2. EXPERIMENTAL ARRANGEMENT

Trace gas emissions by fruit were monitored using detectors based on photoacoustic spectroscopy and infrared lasers. In these detectors a gaseous sample is illuminated by an infrared laser and the molecules become vibrationally and rotationally excited if the light frequency matches the absorption frequency of one of the constituents. Due to transfer of the ro-vibrational excitation energy into kinetic energy by gaseous collisions the gas experiences a temperature rise. Modulating the light intensity yields temperature fluctuations and hence pressure fluctuations (= acoustical waves) at the same modulation frequency. The pressure fluctuations are ideally recorded by a microphone. The intensity of the generated sound is proportional to the concentration of absorbing molecular gas and the laser light intensity. Therefore high power light sources such as lasers are required for sensitive trace gas detection. The gas sample from the fruit is flushed through a detection cell; this photoacoustic (PA) cell is shaped like an 'organ tube' to amplify the acoustical signal and to reduce interfering sounds from the surroundings.

Two types of PA detectors were operated in the current study; one based on a CO laser using three PA cells and the other system utilizes a CO_2 laser and is equipped with a single PA cell. Both systems will be briefly described, a more extensive description of these detectors can be found in (Oomens et al., 1998; Persijn et al., 2000) and (Woltering et al., 1988; de Vries et al., 1996), respectively.

Figure 1 shows the experimental arrangement for the CO laser-based detector. To enhance the infrared light intensity through the photoacoustic cell, it is placed within the laser cavity. This way an order of magnitude increased gas detection sensitivity is obtained (Harren et al., 1997). The CO laser itself can operate in two separate infrared wavelength regions. The wavelength region of 2.8–4 μm is suitable for detecting molecules with a C-H stretch vibration around 3 μm; e.g. methane, ethane, and pentane. The region of 5–8 μm is well suited for the detection of e.g. ethanol, acetaldehyde and nitric oxide. Over both wavelength regions the laser generates 400 laser lines with a maximum laser power up to 30 Watt. To measure gases emitted from fruit the crop can be enclosed in a glass cuvette of various sizes (de Vries et al., 1996). A continuous gas flow through this cuvette (typical flow rate 2 litre per hour) carries released volatile compounds towards the detection cell. In between a liquid-nitrogen cooled trap reduces the concentration of interfering compounds such as water vapour. Water vapour has a vibrational absorption band in the mid-infrared region and due to its high ambient concentration (about 1–2%) it blocks spectroscopical information from other gases at low (part per million) concentrations. The temperatures of the liquid nitrogen cooled trap can be maintained constant, at –160 °C, –120 °C, and –60 °C. For the detection of ethanol and CO_2 the –60 °C trap is used removing water vapour, while for detection of acetaldehyde the –120 °C trap is used suppressing amongst others ethanol concentration levels. From each of the temperature levels the gas flow enters

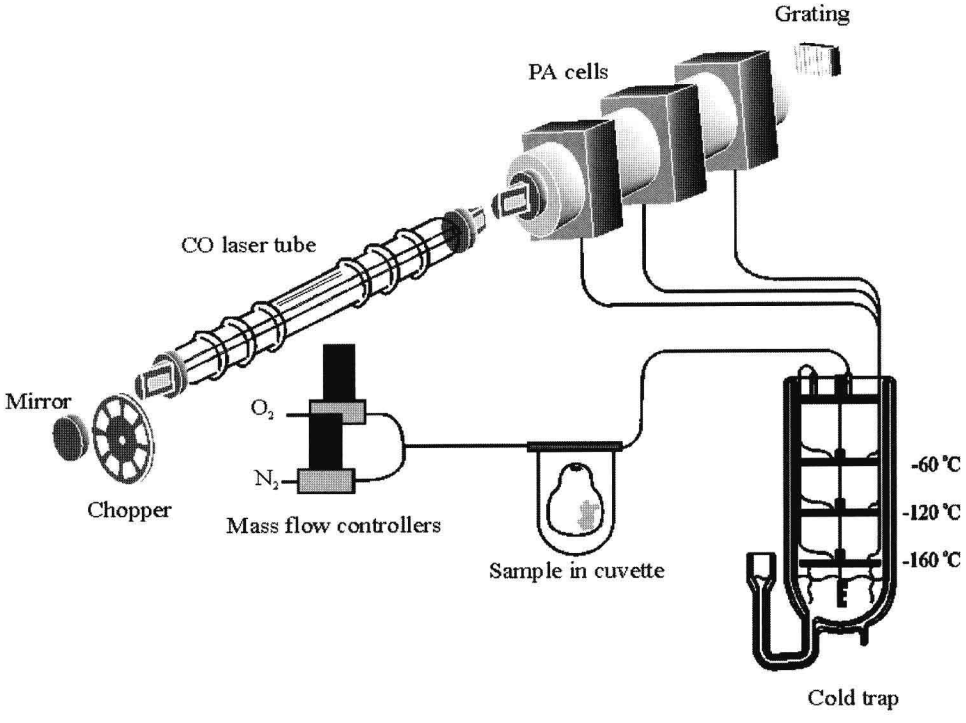

Figure 1. Schematic overview of the experimental set-up. A gas mixture of O_2 and N_2 is made by using a set of electronic mass flow controllers. This carrier flow transports released volatile compounds to a cold trap that removes interfering compounds on basis of their vapour pressure (mainly H_2O vapour). Subsequently, the gas flow enters one of the PA cells. The concentration of the different compounds is determined by measuring the PA signal on a set of laser lines. Individual laser lines are selected by rotating a grating.

a separate photoacoustic cell. By recording the PA signal in each of these cells on a set of laser lines multi-component gas mixtures can be analysed. Depending on the kind and number of compounds to be analysed the time to get a set concentrations varies; approximately one minute per compound is required.

The experimental set-up for the CO_2 laser based detector is very similar. This laser covers the 9–11 μm wavelength region where it shows laser action on 80 laser lines with a maximum laser power up to 100 Watt. This detector is especially applied to monitor C_2H_4. Due to the very strong C_2H_4 absorption band a detection limit as low as 20 ppt (1 ppt = 1 part per trillion = $1{:}10^{11}$) has been obtained for this gas. The cold trap of this system uses only a single trap at a temperature of about –150 °C.

To show the high sensitivity of both detectors, extrapolated detection limits (signal-to-noise ratio is 1) are shown for several gases of biological interest (see Table 1). Interference by other compounds is supposed to be negligible (detection limits become worse when gas mixtures with a number of absorbing compounds are analysed).

Table 1. Extrapolated detection limits for various biologically interesting gases utilizing PA detectors based on CO_2 and CO lasers (1 ppb = $1{:}10^9$).

Name	Formula	Detection limit (ppb)
Acetaldehyde	CH_3CHO	0.3
Ammonia	NH_3	0.02
Dimethyl sulphide	$S(CH_3)_2$	1
Ethane	C_2H_6	0.5
Ethanol	C_2H_5OH	3
Ethylene	C_2H_4	0.02
Methane	CH_4	1
Nitric oxide	NO	1
Water vapour	H_2O	30

Experiments were performed on single fruits to prevent averaging out of individual fruit responses and therefore the results shown here do not represent the mean of many replicates but show the behaviour of a single piece of fruit. However, similar emission patterns were observed in other analysed fruits although individual responses may vary somewhat.

2.1. Ethylene release by tropical fruits grown in Indonesia

Ethylene is a naturally produced, gaseous plant growth regulator that has numerous effects on the growth, development and storage life of many fruits (Salveit, 1999). It exerts its effects at concentrations at the part per million level or even below. In climacteric fruit C_2H_4 promotes its own synthesis via a positive feedback mechanism (i.e., autocatalytic C_2H_4 production). Here, a survey was made of the ethylene emission by a variety of tropical fruits grown in Indonesia. C_2H_4 emission was monitored with the CO_2 laser-based PA detector. Single fruits were measured in a ripe condition and were suitable to be served as table fruits. In addition, the ethylene release by mangosteen (*Garcinia mangostana*) and avocado (*Persea Americana*) are discussed.

Mangosteen has a thick, clear green cortex that changes to dark purple or red-purple during ripening. Enclosed by the rind are 4–8 edible white segments. The flavour is slightly acidic, but sweet (Nakasone et al., 1998). Commercial production has been limited by slow growth, long juvenile periods of 10–15 years and short shelf life of fruit when mature (Wiebel et al., 1992). Mangosteen is considered by many to be the most delicious of all tropical fruits.

Avocado fruit is in such a way an unusual fruit that it does not require picking as soon as the fruit matures. Some cultivars can remain on the tree for more than six months after maturity (Salunkhe et al., 1984). The start of the respiratory peak coincides with a drastic loss of firmness due to cell wall degradation (Pesis et al., 1978).

Figure 2 presents ethylene releases by mangosteen and avocado along with the ripening process. The ethylene emission of mangosteen shows a, 4 days, climacteric peak with relative high pre- and post-climacteric ethylene release levels. For

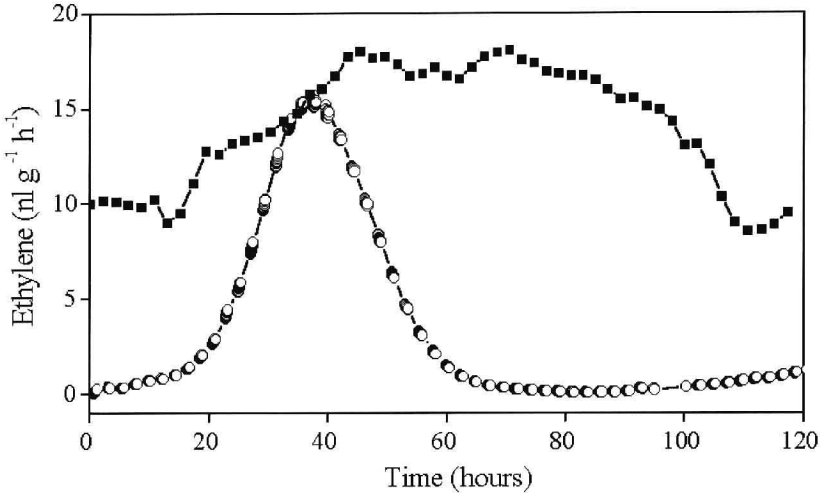

Figure 2. Ethylene release by mangosteen fruit (■) and avocado fruit (○, cv. Fuerte), stored at room temperature. Both fruits show a climacteric peak but pre- and post-climacteric levels are very low for avocado in contrast to mangosteen. For avocado, ethylene release increases again two days after the climacteric peak as the fruit starts to deteriorate.

avocado the ethylene release is during the pre-climacteric period up to 50-fold lower as compared to the 2 days lasting climacteric peak.

Table 2 shows mean values of single fruit measurements in a period where no noticeable variation in ethylene emission was observed. The ethylene emission normalised by weight ranges over more than 3 orders of magnitude. Note that the presented data only serve to give an indication of the fruits' ethylene emission since during ripening the ethylene emission is not constant but shows, especially for climacteric fruits, very large fluctuations (see Figure 2).

3. ETHANOL AND ACETALDEHYDE RELEASE BY AVOCADO DURING ANAEROBIC AND LOW OXYGEN STORAGE

The second application concentrates on the release of the fermentative metabolites acetaldehyde and ethanol by avocado stored under anaerobic conditions. Furthermore, the effect of the post-anaerobic (and post-hypoxic) addition of oxygen is presented.

3.1. Time evolution of fermentation process for avocado kept under anaerobic conditions

To study the fermentative behaviour of avocado the fruit was placed in a cuvette flushed by a gas flow of pure nitrogen. Under these conditions the fruits' gas release of ethanol, acetaldehyde, and CO_2 was recorded simultaneously (Figure 3) using the CO laser-based detector.

Table 2. Ethylene emission rates of a variety of tropical fruits found in Indonesia. Data are mean values of single fruit measurements in a period where no noticeable variation in ethylene emission was observed.

Fruit name	Scientific name	Fresh weight (g)	C_2H_4 release (nl g^{-1} h^{-1})
Banana (ambon)	*Musa paradisiacal*	150	1
Banana (raja)	*Musa paradisiacal*	175	0.9
Durian	*Durio zibethinus*	1700	1
Gayam	*Inocarpus fagiferus*	550	0.8
Keben	*Barringtonia asiatica*	440	0.01
Kepel	*Stelechocarpus burahol*	170	0.01
Kuweni	*Mangifera odorata*	560	0.03
Langsat	*Lansium domesicum*	13	0.3
Longan	*Euphoria longuna*	3.9	0.2
Melinjo	*Gnetum gnemon*	1.6	0.1
Mundu	*Garcinia dulcis*	95	2
Pace	*Marinda citrifolia*	110	0.03
Rambutan	*Nephelium lappaceura*	18	0.02
Salak	*Salacca edulis*	49	0.06
Sapodilla (kecik)	*Manilkara kauki*	51	4
Sapote (manila)	*Achras zapota*	16	3
Soursop	*Annona muricata*	300	20
Starfruit	*Averrhoa carambola*	62	0.8

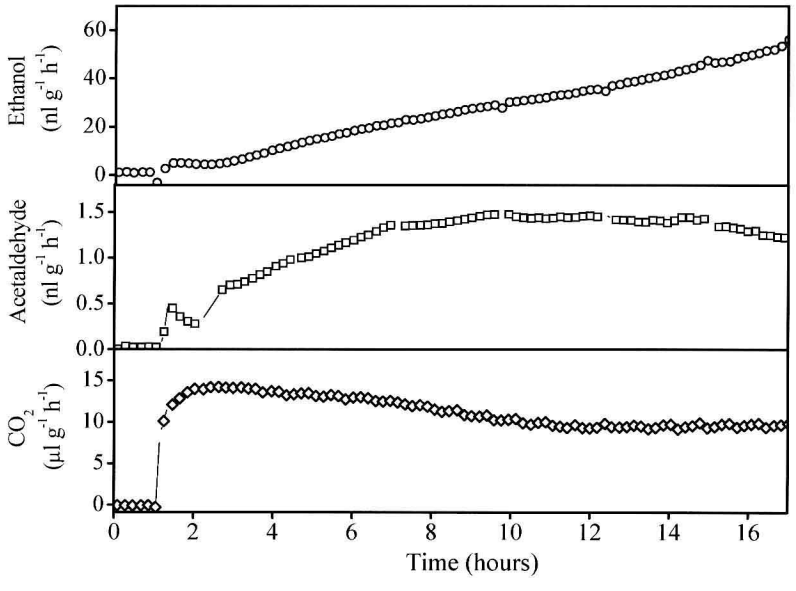

Figure 3. At $t = 1$ hour an avocado was placed in the cuvette under anaerobic conditions. Acetaldehyde release becomes stable after about 10 hours under anaerobic conditions while the ethanol release increases linearly with time during the entire course of the experiment (linear fit: R = 0.9975, N = 157, $P < 0.0001$). Similar emission patterns have been observed for numerous other fruit (see text).

Shortly after putting the fruit under anaerobic conditions acetaldehyde release increases followed by a levelling-off. After about 10 hours under anaerobic conditions the acetaldehyde emission rate becomes stationary. In contrast to this the ethanol release increases linearly over the entire time course of the experiment. The time evolution of acetaldehyde and ethanol release follows a pattern that is characteristic for a large number of fruit like bell pepper (Oomens et al., 1998; Imahori et al., 2000), salak (a tropical fruit, unpublished), and pear (Persijn et al., 2000). Furthermore, a linear increasing ethanol evolution was observed in Brussel sprouts and Jonagold apples under anaerobic conditions for periods up to 15 and 50 days, respectively (Schouten, 1995). Acetaldehyde is released at a very low rate indicating an efficient conversion of acetaldehyde to ethanol. This is in agreement with the observation made by Kader, and Ke & co-workers who showed that activity of alcohol dehydrogenase, the enzyme that reduces acetaldehyde to ethanol, is extremely high in avocado (Ke et al., 1995; Kader, 1995). CO_2 is released at a much higher rate than ethanol, which might seem contrasting since the formation of ethanol in the fermentation process is normally presented by $C_6H_{12}O_6 \rightarrow 2\ CO_2 + 2\ C_2H_5OH$. However, ethanol is also converted to other substances such as ethyl acetate (Yearsley et al., 1996) while CO_2 arises partly from other processes (Fidler, 1951).

3.2. Post-anaerobic and post-hypoxic addition of O_2

Figure 4 shows the effect on the acetaldehyde emission by introducing a small amount of oxygen (1%) to the fruit.

Addition of only 1% O_2 results in a fast and high upsurge in acetaldehyde. Analyzing different avocado fruits, a 10 to 60-fold increase was found (average 32 ± 15) due to post-anaerobic addition of O_2, which is much higher than found in other fruits and plants. Bell pepper gave on average a 4-fold increase (Oomens et al., 1998) while apple (cv. Jonagold) and tobacco leaves only yielded a 2-fold

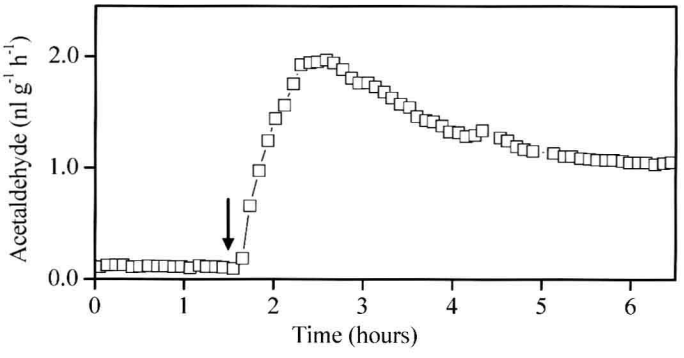

Figure 4. Release of acetaldehyde by avocado fruit stored under anaerobic and post-anaerobic conditions. At the start of the measurement the fruit has been exposed to anaerobic conditions for one day. Post-anaerobic addition of 1% O_2 at time indicated by an arrow leads to a fast and high upsurge in the acetaldehyde release due to oxidation of accumulated ethanol. The release of ethanol remains constant during the entire experiment (result not shown).