Can Ethylene, A Simple Gaseous Hydrocarbon, Be Considered as A Plant Hormone?

Frank Veroustraete
University of Antwerp
Belgium

COLUMN ARTICLE

Introduction

In addition to growth hormones auxins, cytokinins, gibberellins, and the abscission hormone abscisic acid, ethylene is a different type of plant physiological process regulator. Cited compounds all control one or another type of plant physiological process. In this editorial, we focus on the least structurally complex as well as the only gaseous molecule of all plant physiological regulators e.g., ethylene.

Ethylene has been demonstrated to be associated with fruit ripening. It has therefore been baptised as a plant fruit ripening hormone. But ethylene is an unusual plant growth, or fruit ripening regulator because it is a volatile gas (C_2H_4) with ethene as its IUPIAC name and actually – as far as known today - the only gaseous plant regulator in the plant kingdom. Two hundred years ago, when gas street lamps were installed in city streets, trees growing close to these lamp posts developed twisted, thickened trunks, shedding their leaves earlier than expected. These effects were found to be induced by high concentrations of ethylene volatilizing from the gas lamps at that time.

Plant tissues - leaves, dark grown stems or stem nodes and lower plant thalli - actually all living plant tissues produce ethylene. This ethylene production depends in magnitude on tissue age and the presence or absence of light (active photosynthesis). Moreover, the younger a plant tissue, the higher its ethylene production and the higher its ATP (Adenosine-tri-phosphate) content indicating a higher turnover of the energy metabolism of the plant tissue. It has also been demonstrated that ethylene production is under control of phytochrome as well. A difference is also observed in the wound response of higher and lower plants. Higher plants show a surge in ethylene production when wounded (or cut) as opposed to lower plants, which do not elicit this ethylene surge after wounding (cutting) [1]. The phenomena just described led to a sometimes vigorous discussion on the hypothesis whether ethylene is a classical plant hormone or just a metabolic product under the control of plant (energy) metabolism.

Ethylene R&D

A long lasting R&D effort was initiated from the sixties onward, to find a receptor for ethylene, which would promote it to the status of a classical (plant) hormone. Only during the last decennium, various studies suggested a number of components to be part of an ethylene signalling pathway and led to increasingly refined models for signal transduction [2,3,4]. Research results elicited an ethylene receptor (ETR1,) with multiple roles in regulating plant growth and development. The basis for these multiple roles is still unknown but each role seems to have a unique receptor and receptor domain requirements. Whether the mechanisms underlying these different roles for ETR1 involves multiple outputs from the receptor, a modulation of receptor levels or its localization, unique protein-protein

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interactions or some combination of these factors, is still an open question. Hence, a role as hormone in plants for ethylene is not fully corroborated, by a complete description of a signal transduction pathway involving ethylene [4].

Is Ethylene a ripening hormone?

The best-known effect of ethylene is the promotion of fruit ripening. Ethylene stimulates (regulates?) the conversion of starch and acids to sugars. This process is very often accompanied (or initiated) by the so-called climacteric. A climacteric in fruits, is a surge in respiration in the fruit tissue cells, delivering the energy for the conversion of starch and fruit acids into sugars, converting the fruit tissue from a sour to a sweet taste. This respiration surge is accompanied (or initiated?) by a strong increase in ethylene production as well. The climacteric is a stage of fruit ripening associated with a rise in respiration and increased ethylene production. Apples, bananas, melons, apricots, tomatoes (among others) are climacteric fruit types. Citrus, grapes, strawberries are non-climacteric fruits hence, they ripen without the respiratory and ethylene burst. Hence ethylene is strongly correlated with the ripening of fruit from different plant species, but this process is certainly not universal in the plant kingdom and a correlation does not imply a regulatory function in ripening either. Nevertheless, people sometimes store unripe fruit, such as avocados, in sealed bags to accelerate ripening. Ethylene released by the first fruit to mature will speed up the maturation of the remaining fruits in the bag.

Figure 1: The ripening of dates.

Hence, ethylene from one fruit in a closed recipient reaching its climacteric, promotes the ripening of the other fruits in the recipient. This is observed with the ripening of dates, apples and tomatoes, but in principle also other climacteric fruits. Therefore, the commercial importance of ethylene as a ripening promoter of fruits of different (climacteric) plant species is without question. Moreover, ethylene not only accompanies ripening and especially the climacteric, but also promotes an equal phasing in time of a batch of ripening fruits. This principle is applied at a very large scale in fruit cargo ships transporting for example bananas from the region of production (South and Central America) to many ports in the Northern hemisphere (Northern America, Europe), for bananas to be sold on the food markets.

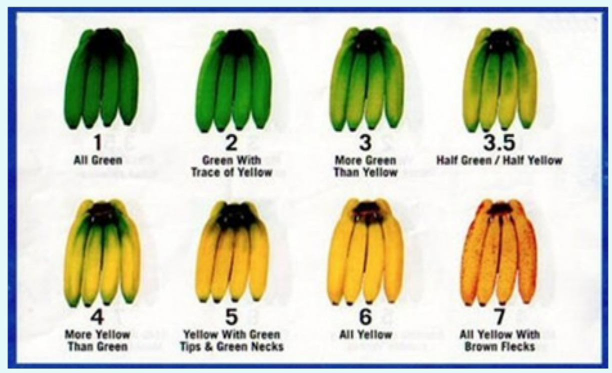

Figure 2: The 8 ripening stages of bananas, from unripe (1) to ripe (7).

When the bananas arrive in the port of destination they have all ripened to about the same ripening stage (3.5 to 4, as illustrated in Figure 2). Evidently it is important that bananas - when sold in a warehouse - are not in different stages of ripening, but preferably in the same ripening stage and readyfor consumption (ripening stages 5 and 6 as shown in Figure 2).

As a conclusion, I would like to derive some practical suggestions with regard to ethylene use in ripening processes of climacteric fruits. Ethylene is a plant growth regulator which postharvest physiologists have studied in an attempt to understand, especially fruit ripening. I am convinced that the monitoring of ethylene can become an extremely valuable tool in the fruit industry's attempts to continue to

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improve ripe fruit quality and taste. Ethylene monitoring, allowing to control the ripening process, should become commonplace in the fruit industry. Research efforts on ethylene need to be directed towards the commercial application of ethylene monitoring technology and hence, the development of fruit ripening management systems.

Ethylene monitoring techniques

Monitoring of ethylene (and CO_2) production very often completes the picture of any ethylene research topic or application. Therefore, the search for suitable ethylene monitoring methods for various plant species either in the field, greenhouse, laboratory or storage facility, is strongly advised [5].Three main categories of methods for ethylene monitoring of plants and fruits can be cited:
1) GC detection; 2) Electrochemical sensing 3) Optical detection.

Figures 3, 4 and 5 demonstrate the three monitoring principles here above.

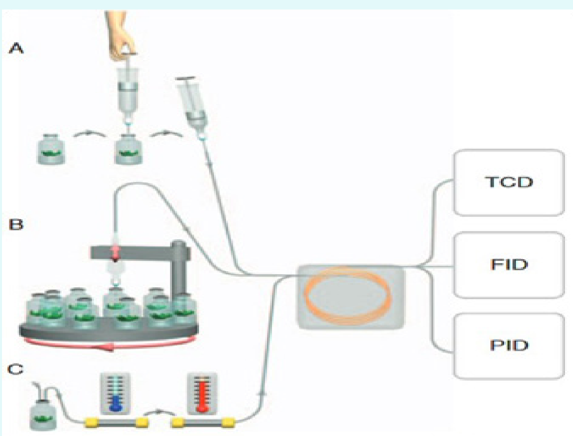

Figure 3: Gas chromatographic monitoring. Several configurations have been developed using gas chromatographs (GC's). Both sampling and injection into the column have been improved over the years. (A) Manual GC injection has been done with syringes. (B) Auto-injector-facilitated injection brought higher accuracy and allowed to process a larger number of samples. (C) (Cryogenic) Adsorption/desorption units are used to accumulate ethylene for several minutes to increase the detection limit to the ppb range.

Several detection schemes have been implemented using a less sensitive detector, such as the thermal conductivity detector (TCD). Later on detectors sensitive to hydrocarbons – especially the flame ionization detector (FID) – or for aromatic and olefin hydrocarbons – the photo-ionization detector (PID) – have been developed and became the most commonly used detector technologies for ethylene monitoring based on the use of GC's.

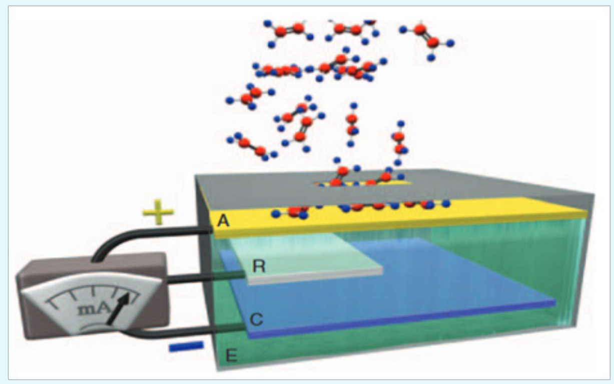

Figure 4: Electrochemical sensing. With this technique, ethylene diffuses through a barrier into the sensor, which consists of a sensing electrode (anode, A), a counter electrode (cathode, C) and a reference electrode (R) covered by a thin layer of an electrolytic solution (E). If an electrical potential is applied to the anode (most recently made of gold particles) ethylene is catalytically oxidized, resulting in a current change proportional to the ethylene concentration. An advantage of this technique is its capacity for continuous monitoring of ethylene. A disadvantage is its low sensitivity.

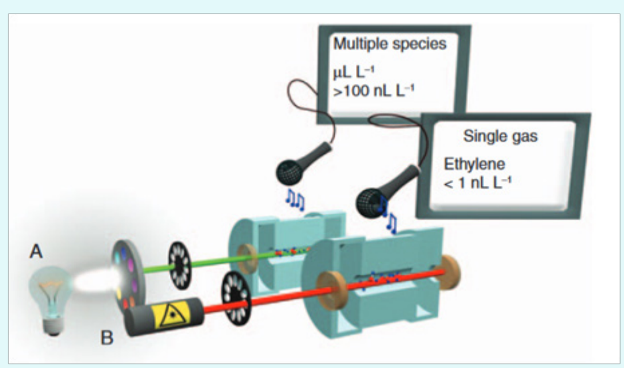

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Figure 5: Non-dispersive versus laser-based sensing using photo-acoustic spectroscopy. With this monitoring principle, light is generated by 1) a broadband light source of which light passes through a filter wheel (A) or laser light (B) directed into a cell where it is absorbed by ethylene molecules and converted into heat. By switching the light on and off with a mechanical chopper the temperature changes periodically, giving rise to a periodic pressure change (ultrasound).The resulting acoustic energy is detected by a miniature microphone. As it happens, the sound intensity is proportional to the concentration of the absorbing gas molecules present in the cell. Non-dispersive sensors detect multiple gas species at ppm level concentrations (e.g. ethylene and interfering gases) by using optical filters. Laser-based sensors however, using a single-frequency polarised light source, are more selective and provide the lowest detection limits so far (fractions of ppb's of ethylene).

Clearly, the potential of laser acoustic monitoring is the most appealing, since it provides for a continuous monitoring of ethylene concentrations lower than a ppb. This is exactly what is needed to monitor ethylene in open flow systems, storage rooms or a ship's cargo compartment. This leads to the conclusion that a monitoring technique enabling the management of the ripening process of many climacteric fruits is for sale on the market as we speak. Hence, time for fruit carrier and distribution companies to make use of it and reduce the risk on overripe fruit batches, which no consumer will buy (see the bananas in ripening stage 7, Figure 2). Overripe fruits represent a financial loss for the producer, carrier and distributor as well as an unwanted loss of food as well.

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