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# Ethylene levels associated with fruit and vegetables during marketing

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*Abstract*. Over 700 measures of the level of ethylene in the atmosphere of fruit and vegetable holding areas in wholesale markets, distribution centres, supermarket retail stores and domestic refrigerators were taken over a 3-year period. The lowest ethylene levels were found in supermarket stores with a mean level of 0.017–0.035 µL/L in produce receival, storage and display areas. Levels in the ambient air of wholesale markets and distribution centres were higher at about 0.06 µL/L. Domestic refrigerators were grouped into those that contained or did not contain apples with the ethylene level being much higher at 0.20 µL/L where apples were present and 0.029 µL/L where apples were absent. Using a rating scale, which was developed from published literature on non-climacteric produce, of ≤0.015 µL/L ethylene as a low level where less than 10% of potential postharvest life is lost and ≥0.1 µL/L as a high level where there is higher than 30% loss of postharvest life, suggests that most produce during marketing is held in an ethylene atmosphere where 10–30% of potential postharvest life is lost.

## Introduction

Ethylene is known to enhance postharvest changes in many fruit and vegetables. With climacteric fruit, ethylene initiates ripening, which is usually undesirable during storage and transport although ethylene is commercially applied to uniformly ripen fruit such as banana just before sale to retail outlets. With non-climacteric fruit and vegetables, ethylene promotes senescence with typical effects being accelerated loss of green colour (Wills and Kim 1996; Wills *et al*. 1999) and growth of decay microorganisms (Wills and Kim 1995), but it is also used beneficially to degreen citrus fruit such as oranges. Ethylene can also induce physiological disorders and chilling injuries in both climacteric (Wills and Gibbons 1998) and non-climacteric produce (Kim and Wills 1995; Wills *et al*. 1999). Maintaining a low level of ethylene in the atmosphere around fruit and vegetables is therefore well recognised as important in maximising postharvest life. However, for any particular produce, endogenous metabolism is not the only source of ethylene that needs to be considered. It can come from other produce or plant materials held in the same storage chamber, or from exhaust gases emanating from coal and petroleum combustion devices operated in the vicinity (Kader 1985; Wills *et al*. 1999).

A level of 0.1 µL/L is often cited as the threshold level of ethylene below which no physiological effects are induced (Knee *et al*. 1985; Wills *et al*. 1989). This is despite Peacock (1972) showing that there was no effective threshold level of ethylene for the ripening of bananas. More recently, a series of laboratory studies by Wills and colleagues (Kim and Wills 1995; Wills and Kim 1995, 1996; Wills and Wong 1996; Wills *et al*. 1999) has shown that a wide range of non-climacteric produce is adversely affected by the presence of ethylene at concentrations well below 0.1 µL/L. They found an increase in postharvest life across 30 types of produce when the ethylene concentration was reduced from 0.1 µL/L to <0.005 µL/L, the lowest concentration that could be measured. The findings imply that there is no 'safe' level of ethylene that does not cause a deleterious effect on postharvest life.

The extent to which the postharvest life of fruit and vegetables is affected by ethylene in the marketing system has had limited attention. Morris *et al*. (1978) surveyed the levels of ethylene in the external atmosphere and in packed cartons of lettuce during storage and distribution and found that ethylene accumulated to levels up to 2–3 µL/L. This paper reports the results of surveys conducted in 1997–99 that determined the level of ethylene present in handling



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and storage areas in the Sydney fruit and vegetables wholesale markets, produce distribution centres, supermarket retail stores and domestic refrigerators.

## Materials and methods

*Atmosphere collection sites*

The level of ethylene was examined in samples of the atmosphere collected from:

(i) Sydney Fruit and Vegetables Wholesale Markets, Flemington. Samples of atmosphere were collected every 3 months over a 12-month period from inside the packages of a wide range of fruit and vegetables on the floor of the markets during the early morning trading period, and from the general atmosphere inside trading and holding areas on the markets site.

(ii) Commercial produce distribution centres in the vicinity of the wholesale markets that were involved in holding large consignments of various produce before dispatch to the markets or directly to supermarkets. Distribution Centre 1 (DC1) held kiwifruit from New Zealand as well as avocados, dates, asparagus and garlic from other areas for distribution to a supermarket chain. Distribution Centre 2 (DC2) stored and packed apples, kiwifruit, mandarin and avocados for a supermarket chain, with fruit stored for 2–30 days depending on market requirements. Distribution Centre 3 (DC3) distributed a wide range of fruit and vegetables to the various supermarkets around New South Wales with dispatch normally within 24 h of arrival. Repeat visits were made on at least 5 occasions to each DC to collect a sample of the atmosphere in the storage rooms and from the external loading area.

(iii) Supermarket retail stores. A sample of atmosphere was collected from the produce receival area, storage room and display area in 7 stores of a supermarket chain in the Central Coast and Sydney region with at least 5 repeat visits made to each store. The receival area is where produce is held on unloading at the supermarket before being transferred to either the storage room or to the display area in the store. The receival area is generally not temperature controlled while the cool store is nominally held at 5°C and the general display area is held at 23°C.

(iv) Domestic refrigerators. The atmosphere in the crisper section of the refrigerator in 30 households was collected on three occasions by a resident of the house.

*Analysis of ethylene*

Atmospheric sample in the commercial marketing establishments were collected by inserting a polyethylene tube into the package of produce or storage chamber and withdrawing a gas sample into a 100-mL syringe, which was then sealed. Samples from the domestic refrigerators were obtained by inserting, just before retiring, the open end of the collection tube into the crisper section of each refrigerator while the syringe remained outside the refrigerator. The atmosphere was collected in the syringe the next morning before the refrigerator door was opened.

All gas samples were transported to the laboratory where an aliquot (1 mL) was analysed for ethylene content by flame ionisation gas chromatography (Gow-Mac GC Series 580, Bridgewater, NJ) using a stainless steel column (600 by 1 mm) packed with Porapak Q (80–100 mesh) (Supelco, Bellefonte, PA) with operating conditions of injector and detector temperatures of 150°C, column temperature 110°C with nitrogen carrier gas flow rate 30 mL/min, hydrogen flow rate of 30 mL/min and air flow rate of 300 mL/min. Samples were compared with a standard concentration of ethylene in air 0.16 ± 0.05 μL/L (BOC Gases, Sydney). The sensitivity of the instrument allowed detection of ethylene in 1 mL of atmosphere at 0.004 μL/L.

## Results and discussion

*Wholesale markets*

Table 1 shows the range of ethylene levels in the 562 samples of atmosphere collected over the 12-month period. As might be expected there was considerable variation between different produce as evidenced by the high standard deviations of the various produce categories relative to the respective means. Overall, the highest level of ethylene was found in the atmosphere inside packages of climacteric fruit, with a mean value of 0.22 μL/L obtained over the study. The mean level of ethylene around leafy vegetables and other non-climacteric produce was about 0.06 μL/L, which was similar to that present in the ambient air in the produce holding areas. It is suggested that climacteric fruit are a major source of ethylene in wholesale markets, although there would also be a significant contribution from the substantial movement of trucks and gas-powered forklift vehicles around the holding areas. This would give rise to the higher than normal (0.001–0.005 μL/L) level of ethylene in ambient air (Abeles *et al*. 1992). The ethylene level around non-climacteric produce would seem to be in equilibrium with the surrounding ambient air rather than adding to the ambient air.

*Distribution centres*

The level of ethylene present in the atmosphere of the distribution centres is given in Table 2. DC1 showed a range of concentrations in the 5 storage rooms. The highest levels were in the rooms containing avocados, with the level rising from about 0.6 μL/L in the room of unripe avocados, to about 0.9 μL/L in the ripening room (ripening was activated by increasing the temperature to 20°C and not by the application of ethylene), and to about 1.4 μL/L in the ripe fruit holding room. Flow of ethylene from the avocado rooms probably accounts for the level of 0.28 μL/L in the empty storage room and could account for much of the ethylene in the room with unripe kiwifruit (0.23 μL/L). Such a residual ethylene level would not be conducive to maintaining kiwifruit in an unripe condition. The ethylene level of 0.07 μL/L in the air outside the storage complex was much higher than in normal ambient air.

Lower levels of ethylene, 0.12 and 0.24 μL/L, were present in the storage rooms of DC2 that contained kiwifruit and apples, respectively. The difference in ethylene concentration between the 2 rooms is much smaller as apples evolve ethylene at a much higher rate

**Table 1. Level of ethylene (mean ± s.d.) in samples of atmosphere collected from the Sydney Wholesale Markets over a 12-month period**

*n*, number of atmosphere samples collected

| Area of market | Ethylene concentration (µL/L) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *n* | Spring | *n* | Summer | *n* | Autumn | *n* | Winter | Mean |
| Climacteric fruit | 61 | 0.158 ± 0.129 | 46 | 0.495 ± 1.29 | 12 | 0.281 ± 0.166 | 18 | 0.066 ± 0.031 | 0.222 |
| Leafy vegetables | 42 | 0.074 ± 0.022 | 52 | 0.082 ± 0.058 | 38 | 0.061 ± 0.029 | 18 | 0.042 ± 0.021 | 0.070 |
| Other non-climacteric produce | 87 | 0.067 ± 0.027 | 67 | 0.061 ± 0.073 | 49 | 0.067 ± 0.047 | 36 | 0.046 ± 0.019 | 0.061 |
| Trading areas | 9 | 0.063 ± 0.037 | 9 | 0.070 ± 0.043 | 9 | 0.066 ± 0.051 | 9 | 0.050 ± 0.032 | 0.062 |

than unripe kiwifruit (Kader 1980). This suggests that ethylene readily flows from the apple room into the kiwifruit room. The ethylene level in the ambient air at 0.07 µL/L was similar to that in the air outside DC1.

The cool rooms of DC3, both of which housed many kinds of fruit and vegetables, contained a similar level of ethylene at 0.08 µL/L, which was lower than in the fruit storage rooms of DC1 and DC2. The ethylene level in the ambient air at 0.03 µL/L was also lower than that around DC1 and DC2.

*Supermarket stores*

Table 3 shows the level of ethylene in the atmosphere of receival, storage and display areas of supermarket retail stores. A similar trend was seen in all 7 stores, with the highest level of ethylene present in the storage area and the lowest level in the display area. The relativity of concentrations would be that expected from the respective ratios of produce mass to chamber area and the degree of ventilation of each area with external air. However, the levels of 0.035, 0.023 and 0.017 µL/L in receival, storage and display areas, respectively, were all much lower than that present in the atmosphere of the wholesale markets and distribution centres. The level in the storage area was similar to that found for the lowest ambient air in the distribution centres.

**Table 2. Concentration of ethylene (mean ± s.d.) present in the atmosphere of storage chambers in produce distribution centres**

*n*, number of occasions an atmosphere sample was collected

| Area | *n* | Temperature (°C) | Ethylene concentration (µL/L) |
|---|---|---|---|
| | | *Distribution centre 1* | |
| Kiwifruit storage room | 7 | 0 | 0.233 ± 0.055 |
| Avocado arrival room | 4 | 5 | 0.588 ± 0.340 |
| Avocado ripening room | 5 | 20 | 0.896 ± 0.383 |
| Avocado holding room | 6 | 7 | 1.412 ± 0.506 |
| Empty room | 3 | 17 | 0.288 ± 0.105 |
| Ambient air | 4 | 17 | 0.068 ± 0.058 |
| | | *Distribution centre 2* | |
| Kiwifruit storage room | 6 | 0 | 0.127 ± 0.024 |
| Apple storage room | 4 | 0 | 0.243 ± 0.045 |
| Ambient air | 4 | 16 | 0.072 ± 0.066 |
| | | *Distribution centre 3* | |
| Cold room 1 | 5 | 6 | 0.081 ± 0.036 |
| Cold room 2 | 5 | 2 | 0.080 ± 0.006 |
| Ambient air | 5 | 15 | 0.031 ± 0.008 |

*Domestic refrigerators*

The mean value of ethylene found in the crisper section of 30 domestic refrigerators was 0.10 µL/L but there was considerable variation in levels, ranging from 0.011 to 0.59 µL/L. Figure 1 gives the distribution of ethylene levels in individual refrigerators and shows that about 50% of refrigerators had an ethylene concentration of less than 0.03 µL/L and about 30% higher than 0.1 µL/L. The refrigerators with high levels of ethylene all had apples stored in the crisper section while all the refrigerators at the lower end of the distribution did not contain apples. The mean levels of ethylene in the 2 groups were 0.2 µL/L and 0.029 µL/L for those with and without apples, respectively.

*Rating of ethylene levels*

Since it has been documented that an ethylene concentration of 0.1 µL/L is not a valid concept as a threshold concentration for physiological effect on post-

**Table 3. Ethylene concentration (mean ± s.d.) present in the atmosphere of produce handling areas of supermarket retail stores**

| Store | *n* | Ethylene concentration (µL/L) | | |
|---|---|---|---|---|
| | | Receival | Storage | Display |
| 1 | 14 | 0.033 ± 0.015 | 0.046 ± 0.015 | 0.020 ± 0.007 |
| 2 | 8 | 0.014 ± 0.003 | 0.033 ± 0.015 | 0.018 ± 0.003 |
| 3 | 6 | 0.035 ± 0.030 | 0.047 ±0.024 | 0.020 ± 0.006 |
| 4 | 6 | 0.029 ± 0.021 | 0.042 ± 0.037 | 0.023 ± 0.011 |
| 5 | 5 | 0.013 ± 0.005 | 0.021 ± 0.006 | 0.011 ± 0.004 |
| 6 | 5 | 0.026 ± 0.010 | 0.034 ± 0.012 | 0.017 ± 0.007 |
| 7 | 5 | 0.010 ± 0.001 | 0.022 ± 0.008 | 0.012 ± 0.003 |
| Mean | | 0.023 ± 0.010 | 0.035 ± 0.011 | 0.017 ± 0.004 |

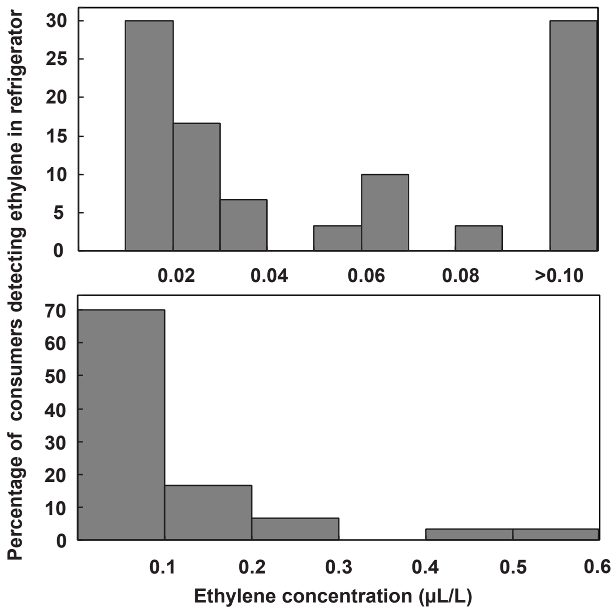


**Figure 1.** Distribution of ethylene levels in domestic refrigerators with or without apples.

harvest fruit and vegetables, it is necessary to establish a new scaling system in order to quantify the undesirable effects of low levels of ethylene on the postharvest life of produce during marketing. This is particularly important for non-climacteric produce, for which ethylene is deleterious throughout the marketing period. The level of ethylene around climacteric produce during marketing would only be of importance when pre-climacteric fruit was being stored for later marketing or transport to distant markets. In most marketing situations, it is normal for fruit ripening to have been initiated or even completed.

For a range of non-climacteric fruit and vegetables, Wills *et al*. (1999) have presented linear regressions for the relationship between postharvest life ($y$) and $\log_{10}$ ethylene concentration ($x$). They presented original data for Chinese cabbage and calculated the regression equations for data given in previously published papers on strawberries (Wills and Kim 1995), iceberg lettuce (Kim and Wills 1995), green beans (Wills and Kim 1996) and 3 Asian leafy vegetables (Wills and Wong 1996). If 0.005 μL/L is assumed to be the lowest possible ethylene concentration that can be achieved in a postharvest situation, then holding any non-climacteric fruit and vegetable in 0.005 μL/L ethylene will generate 100% of its possible postharvest life. The percentage loss in postharvest life at any higher ethylene concentration can then be calculated from the regression equations. Table 4 shows that the percentage loss in postharvest life at 20°C for the 7 non-climacteric produce examined in Wills *et al*. (1999) ranged from 25 to 46% with a mean value of 33%, that is, one-third of the potential postharvest life was lost.

Table 4 also presents the ethylene concentrations at which each produce lost 10 and 30% of its potential postharvest life. A loss of 10% could be considered to be the upper limit for an acceptable postharvest environment, while 30% could be the lower limit for an unacceptable environment. The data show that a 10% loss in postharvest life occurred at an ethylene level of 0.010–0.018 μL/L, with a mean value of 0.013 μL/L, and a 30% loss occurred at 0.035–0.221 μL/L, with a mean value of 0.109 μL/L. The range in ethylene-sensitivity between different types of produce is not unexpected and has resulted in segregating produce into those that are sensitive and those less sensitive to ethylene (Table 4).

Overall, it would seem that, during marketing, all non-climacteric produce should be held in air containing ≤0.015 μL/L ethylene to maximise postharvest life. The level of ethylene that would lead to substantial loss in postharvest life during marketing would seem to be >0.05 μL/L for sensitive produce and >0.15 μL/L for less sensitive produce. Since most marketing situations involve the holding of many types of produce in 1 chamber, a compromise upper limit for ethylene concentration could be 0.1 μL/L, which is the previously considered threshold level. To more accurately define the lower and upper limits of ethylene tolerance of non-climacteric produce, quantitative data on the effects of ethylene level on the postharvest life of additional fruit and vegetables are required.

**Table 4. Relationship between postharvest life at 20°C and environmental ethylene level for seven non-climacteric fruit and vegetables**

| | Postharvest loss at 0.1 μL/L (%) | Ethylene conc. producing a 10% loss (μL/L) | Ethylene conc. producing a 30% loss (μL/L) |
|---|---|---|---|
| | *Sensitive produce* | | |
| Chinese cabbage | 38 | 0.011 | 0.055 |
| Lettuce | 42 | 0.010 | 0.043 |
| Strawberry | 46 | 0.010 | 0.035 |
| Mean | 42 | 0.010 | 0.044 |
| | *Less sensitive produce* | | |
| Beans | 25 | 0.017 | 0.187 |
| Bok choi | 24 | 0.018 | 0.221 |
| Choi sum | 29 | 0.014 | 0.106 |
| Gai lan | 28 | 0.014 | 0.117 |
| Mean | 27 | 0.016 | 0.158 |
| Overall mean | 33 | 0.013 | 0.109 |

Application of a rating scale of ≤0.015 μL/L ethylene as an acceptable low level and ≥0.1 μL/L as an unacceptable high level during the marketing situations examined in this study is shown in Table 5. The ethylene level in the ambient air in the wholesale markets was found to have 5% of readings at a low level while in the distribution centres ethylene levels were never low. There were 15–17% of readings in these areas at a high level. This means that most ethylene levels (78 and 85%, respectively) were in the medium range (0.015–0.1 μL/L). Non-climacteric produce in the wholesale markets showed only 10% of the 389 packages with a low ethylene atmosphere and 16% with a high level. The storage rooms at the distribution centres that held both climacteric and non-climacteric produce were predominantly in the high range. The ethylene levels thus suggest that the average loss of potential postharvest life, while non-climacteric produce are held in the wholesale markets or distribution centres, is substantial at 25–30%.

The level of ethylene in the produce handling areas of supermarket retail stores is more favourably rated. Only 2% of readings in the storage areas and none in the display and receival areas were found to be in the high range. About 40% of readings in the receival and display areas were in the low range. Most levels in the storage areas were thus in the medium range. The overall mean ethylene level in the supermarkets of 0.025 μL/L indicates an average loss of potential postharvest life in retail stores of about 15%.

A relatively high proportion of domestic refrigerators (30%) were found to contain a high level of ethylene, while only 17% contained a low level. The crisper section is normally small and often packed for some time with mixed fruit and vegetables. Of the refrigerators which contained apples, 75% were in the high range of ethylene levels. It is clear that where fruit and vegetables are likely to be stored for some time in a refrigerator, apples, or at least the atmosphere emanating from apples, should be isolated from other produce.

**Conclusions**

The survey has found that ethylene levels in the atmosphere surrounding fruit and vegetables during marketing is reducing the postharvest life of non-climacteric produce. The levels present in the wholesale markets are suggested to result in a moderate reduction of postharvest life while levels in the distribution centres result in a moderate to high reduction. The supermarket retail stores provide the most benign ethylene environment, with levels in the low–medium range. Domestic refrigerators can provide an unfavourable ethylene environment, especially when apples are present.

Although produce may only spend a small proportion of their postharvest life in each marketing situation, the effects of elevated ethylene levels are cumulative. The end result of successive levels of moderate ethylene levels throughout marketing can be a very short life in the hands of the consumer. The industry should be seeking to minimise the impact of ethylene on produce at all stages of the marketing chain. The extended market life that would arise from a reduction in ethylene level during marketing can lead to consumers having greater confidence in the purchase of fruit and vegetables with a resultant increase in sales volume and/or price. Education of consumers in

**Table 5. The percentage of produce storage areas (containing mixed climacteric and non-climacteric fruit or vegetables) where ethylene levels were rated as low, medium or high**

| Situation | *n* | Low (≤0.015 μL/L) | Medium (>0.015–<0.10 μL/L) | High (≥0.10 μL/L) |
|---|---|---|---|---|
| | | *Wholesale market* | | |
| Air | 36 | 5 | 78 | 17 |
| Non-climacteric | 389 | 10 | 74 | 16 |
| | | *Distribution centre* | | |
| Air | 13 | 0 | 85 | 15 |
| Storage room | 35 | 0 | 40 | 60 |
| | | *Supermarket retail stores* | | |
| Receival | 49 | 47 | 53 | 0 |
| Storage | 49 | 8 | 90 | 2 |
| Display | 49 | 39 | 61 | 0 |
| | | *Consumer market* | | |
| Refrigerator | 30 | 17 | 53 | 30 |

appropriate storage in the home would also seem to be a worthy activity.

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