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Australian Journal of Experimental Agriculture

Volume 39, 1999

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Australian Journal of Experimental Agriculture, 1999, **39**, 221–4

Importance of low ethylene levels to delay senescence of non-climacteric fruit and vegetables

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Summary. The storage life of a range of non-climacteric fruit and vegetables was assessed during storage at ambient temperature (20°C) and low temperature (0–5°C) and ventilation with air containing ethylene over the range <0.005–10 µL/L. The storage life of Chinese cabbage and orange was found to be linearly extended with a logarithmic reduction in ethylene concentration. Across 23 kinds of produce, there was about a 60% extension in postharvest life when stored in <0.005 µL/L compared with 0.1 µL/L, the commonly considered threshold level for ethylene action. It is suggested that the threshold level of ethylene action on non-climacteric produce is well below 0.005 µL/L and that the level of ethylene that accumulates around produce in all commercial situations is always much greater than 0.005 µL/L. Hence, any postharvest action that reduces the accumulation of ethylene around non-climacteric produce during marketing will result in an increase in postharvest life.

Introduction

Ethylene is well known to strongly affect many aspects of plant metabolism including the postharvest behaviour of fruit and vegetables. Most studies with fruit and vegetables have focused on climacteric fruit which ripen after exposure to ethylene above a threshold concentration and exposure time. Ethylene is also known to accelerate senescence of non-climacteric fruit and vegetables (Kader 1985) with typical effects being an increase in the rate of yellowing, an increase in microbial growth, induction of physiological disorders, particularly chilling effects, and development of undesirable flavours. A level of 0.1 µL/L is commonly cited as a concentration above which senescence in commercially mature fruit and vegetables is actively promoted (Knee *et al*. 1985; Wills *et al*. 1989). There are, however, surprisingly few controlled studies examining the effect of low ethylene concentrations on non-climacteric produce. Peacock (1972) advocated that for banana there was no critical threshold concentration of ethylene that induces ripening although his studies explored short time exposure to ethylene levels >0.1 µL/L rather than longer exposures to levels <0.1 µL/L. Wills and co-workers have recently examined the effect of atmospheric ethylene levels from 1.0 to <0.005 µL/L and report that the postharvest life of strawberries (Wills and Kim 1995), lettuce (Kim and Wills 1995), green beans (Wills and Kim 1996) and the Asian leafy vegetables, bak choi, choi sum and gai lan (Wills and Wong 1996) was markedly extended as the ethylene level was reduced with the response maintained over the whole concentration range. This paper reports on studies into the effects of low ethylene concentrations on the postharvest life of a further 18 non-climacteric fruit and vegetables, and examines the consistency of the effects between different types of produce and the implications for commercial practice.

Materials and methods

Chinese cabbage (*Brassica pekinensis*), parsley (*Petroselinum crispum*) and chives (*Allium schoenoprasum*) were obtained from the Sydney wholesale markets, 'Valencia' oranges (*Citrus sinensis*) and 'Shogun' broccoli (*Brassica oleracea*) were obtained from conventional farms while 12 types of lettuce (*Lactuca sativa*) of the butterhead type (butter Arizona, butter asmaralda), crisphead type (mignonette, monet, radiccio), leaf type (green and red oak, green and red coral, red velvet and frillice) and cos type (green cos) were obtained from a hydroponic farm on the Central Coast of New South Wales. Studies were replicated with produce obtained on separate occasions. On arrival at the laboratory, individual

 10.1071/EA98123

batches were sorted to select only those of good quality which were randomly distributed into treatment units of an appropriate size. A treatment unit for each batch of produce consisted of about 200 g of Chinese cabbage leaves and stems, 100 g of parsley and chive leaves and stems, 200 g of broccoli florets, 5 orange fruit each of 150 g, and 20 g of cut leaves of each type of lettuce. The treatment units were packed into storage containers which were ventilated continuously with air containing a controlled concentration of ethylene. Produce was held at a constant temperature which ranged from 0 to 20°C.

Controlled levels of ethylene were obtained by mixing 0.1% ethylene gas (BOC, Sydney) with air through flow meters to generate concentrations of 0.01, 0.1, 1.0 and 10 μL/L ethylene in the gas stream which was passed through the containers holding the produce at 20 L/h. The lowest ethylene concentration was obtained by passing air through a column containing alumina impregnated with potassium permanganate (Purafil, Doraville, GA, USA). The concentration of ethylene in the air stream leaving the column was <0.005 μL/L, the limit of detection. The level of ethylene in the gas streams was monitored daily by flame ionisation gas chromatography (Varian 1400, Walnut Creek, CA, USA) using a 90 cm stainless steel column packed with Porapak Q (80–100 mesh) (Supelco, Bellefonte, PA, USA) with operating conditions of oven temperature 50°C, injector and detector temperature 135°C, nitrogen carrier gas flow rate 50 mL/min, hydrogen flow rate 40 mL/min, air flow rate 300 mL/min, and injected gas sample volume 1 mL.

At regular intervals, produce quality was judged visually by a single observer until a sample was considered unacceptable for marketing. The observer assessed sample quality without knowing the treatments applied. Quality in the Chinese cabbages, broccoli, parsley, chives and lettuces was rated on appearance using a scoring scale of 1–5 where 5 is fresh appearance, 4 is slight loss of fresh appearance, 3 is just satisfactory for marketing, 2 is not acceptable for marketing, and 1 is severely degraded; loss of quality in Chinese cabbage and broccoli was defined by leaf yellowing and browning, in parsley and chives by yellowing and in the lettuces by leaf tip browning. Storage life was the time (days) for the mean score of all leaves in the treatment unit to fall below 3. Orange fruit were individually assessed for chilling injury based on the development of dark spots on the skin using a scale of 1–4 where 1 is no dark colour, 2 is <15%, 3 is 25%, and 4 is >30% of the skin surface covered with dark spots; storage life was the time (days) for a treatment unit to generate a mean score of 1.5. To ensure consistency in quality rating over time, an agreed set of quality standards with accompanying photographs was determined before the initial experiment on each commodity. The change in quality data scores over time for each treatment unit of each type of produce was calculated and a linear regression generated. The time for produce quality to fall to the minimum quality standard was derived from the regression equation and taken as the storage life for that treatment unit.

Results and discussion

The data in Table 1 show that the storage life of Chinese cabbage held at 20 and 0°C, which was limited by the development of leaf yellowing and browning, was affected by the concentration of ethylene in the surrounding atmosphere. There was a linear increase in storage life achieved with a logarithmic decrease in ethylene concentration; at 20°C, $y = 2.2 - 1.9x$ (P<0.01) and at 0°C, $y = 14.7 - 13.3x$ (P<0.01), where y is storage life in days and x is $\log_{10}$ ethylene concentration in μL/L. Table 1 also shows a similar effect of ethylene concentration on storage life of orange which at 2.5°C was limited by the appearance of chilling injury. There was a linear increase in the time to develop chilling injury with a logarithmic decrease in ethylene concentration; $y = 67.9 - 18.2x$ (P<0.01).

A logarithmic relationship between storage life and log ethylene concentration was also reported by Wills and Wong (1996) for 3 Asian leafy vegetables. While strawberries (Wills and Kim 1995), green beans (Wills and Kim 1996) and iceberg lettuce (Kim and Wills 1995) have been shown to have an increase in storage life over a similar range in ethylene concentration, the nature of the relationship was not explored. The data presented in the 3 studies were re-calculated and the presence of a significant linear relationship was confirmed between storage life and log ethylene concentration at all temperatures investigated. The calculated equations are: (i) strawberries at 20°C, $y = 0.28 - 0.57x$, and at 0°C, $y = 0.1 - 3.8x$; (ii) iceberg lettuce (to 10% trimming loss) at 20°C, $y = 4.2 - 2.2x$, and at 0°C, $y = 22.3 - 6.2x$; and (iii) green beans at 20°C, $y = 4.6 - 1.7x$, and at 5°C,

Table 1. Storage life (days) of Chinese cabbage and orange held in air containing ethylene at <0.005–10 μL/L

Each value is the mean of two replicates

Temp. (°C)	Ethylene concentration (μL/L) 10	1.0	0.1	0.01	<0.005	l.s.d. (P = 0.05)
			Chinese cabbage			
0		16.1	26.6	38.5	51.1	4.9
20	2.4	2.5	3.5	5.8	6.8	0.8
			Orange			
2.5	56.0	65.8	79.8	89.6	129.5	9.8

Table 2. Storage life (days) of leafy vegetables held in air containing 0.1 and <0.005 μL/L ethylene

Values for broccoli, parsley and chives are the mean of three replicates
Values for the lettuces are from only one replicate

Produce	Temp. (°C)	Ethylene concentration (μL/L) 0.1	<0.005	Difference	Percentage increase	l.s.d. (P = 0.05)
Broccoli	5	14.2	35.1	20.9	147	12.0
Broccoli	20	1.1	2.2	1.1	94	0.45
Parsley	5	22.4	32.1	9.7	43	8.4
Parsley	20	4.9	11.0	6.1	125	2.6
Chives	5	7.2	11.6	4.4	61	4.0
Chives	20	2.7	4.1	1.4	52	0.2
Lettuce type						
Butter Arizona	5	5.7	6.8	1.1	19	
Butter Asmaralda	5	8.0	8.3	0.3	4	
Frillice	5	6.3	9.3	3.0	48	
Green Coral	5	6.3	8.4	2.1	33	
Green Cos	5	5.9	7.5	1.6	27	
Green Oak	5	5.5	7.8	2.3	42	
Mignonette	5	6.1	9.3	3.2	52	
Monet	5	9.2	12.5	3.3	36	
Radiccio	5	6.3	7.0	0.7	11	
Red Coral	5	6.3	8.4	2.1	33	
Red Oak	5	6.1	8.2	2.1	34	
Red Velvet	5	7.0	7.8	0.8	11	
Mean		6.6	8.4	1.9	29	0.6

$y = 18.3 - 3.5x$, where y is storage life in days and x is $\log_{10}$ ethylene concentration in μL/L.

Maintenance of the inverse relationship between log ethylene concentration and storage life to <0.005 μL/L (the lowest concentration that could be measured) for the 8 non-climacteric produce suggests that the threshold concentration for the onset of ethylene action on fruit and vegetables is much lower than 0.005 μL/L, and certainly well below the commonly accepted threshold level of 0.1 μL/L. Table 1 shows that the storage life of Chinese

Table 3. Published data on storage life (days) of non-climacteric fruit and vegetables held in air containing 0.1 and <0.005 μL/L ethylene

Data for strawberry from Wills and Kim (1995), iceberg lettuce from Kim and Wills (1995), green bean from Wills and Kim (1996), and bak choi, choi sum and gai lan from Wills and Wong (1996)

Produce	Temp. (°C)	Ethylene concentration (μL/L) 0.1	<0.005	Difference	Percentage increase
Strawberry	0	4.1	9.6	5.5	134
Strawberry	20	0.6	1.2[A]	0.6	100
Lettuce, iceberg	0	12.1[B]	35.1	23.0	190
Lettuce, iceberg	20	3.5	8.1	4.6	131
Beans, green	5	13.8	20.0	6.2	45
Beans, green	20	4.7	11.0	6.3	134
Bak choi	0	22.0	27.0	5.0	23
Bak choi	20	4.8	6.3	1.5	31
Choi sum	0	22.3	27.7	4.4	20
Choi sum	20	3.7	6.7	3.0	81
Gai lan	0	21.3	26.7	5.4	25
Gai lan	20	3.7	6.0	2.3	62

[A] Ethylene concentration was 0.05 μL/L. [B] Values for lettuce are to 10% trimming loss.

cabbage held in air containing <0.005 µL/L was about 100% of that held in air containing 0.1 µL/L while oranges showed a 60% increase in storage life. Data in Table 2 show that the storage life of broccoli, parsley and chives at both ambient and low temperature was also significantly extended by an average of 66% (range 43–147%) when held in air containing <0.005 µL/L ethylene compared with air containing 0.1 µL/L ethylene. Since the data for each of the 12 fancy lettuces were only from one replicate, statistical analysis was conducted on the pooled data for each treatment and showed a significant 29% increase in storage life at <0.005 µL/L. When previously published data are included (Table 3), a total of 23 non-climacteric produce have now been shown to benefit by a reduction in ethylene concentration from 0.1 to <0.005 µL/L, with the average increase in storage life across the 30 sets of data being 62% which is substantial enough to be of commercial value.

The actual commercial significance of the findings depends on the levels of ethylene that accumulate around non-climacteric produce during current storage, transport and marketing practices. There is limited information on ethylene levels around produce during commercial postharvest operations but a few readings on the atmosphere in packages of strawberries (Wills and Kim 1995), green beans (Wills and Kim 1996) and iceberg lettuces (Kim and Wills 1995) held at ambient temperature at the Sydney wholesale markets found the ethylene concentration ranged from 0.06 to 1.17 µL/L with the average concentration being 0.23 µL/L for strawberries, 0.34 µL/L for green beans and 0.42 µL/L for iceberg lettuce. This study found even higher ethylene levels in 7 stacks of cartons of Chinese cabbage at the Sydney markets; ranging from 0.86 to 1.45 µL/L and averaging 1.09 µL/L.

While a more comprehensive study is required to determine the range of ethylene levels that accumulate around produce during marketing, it would seem that a level of 0.1 µL/L is not uncommon. Furthermore, it would seem that in all practical storage, transport and marketing situations of fruit and vegetables, the level of ethylene will always be above 0.005 µL/L due to the restricted environments generated by packaging containers, the close stacking of containers and exposure to ethylene generated from other produce or sources such as motor exhaust. Since the threshold level for ethylene action is well below 0.005 µL/L, the level of ethylene in commercial situations will always be high enough to have some detrimental effect on the postharvest life of non-climacteric produce. Any postharvest intervention that reduces ethylene levels around produce will therefore have a positive effect on postharvest life.

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Received 20 August 1998, accepted 10 December 1998