REVIEW

Postharvest Physiology and Handling of Fresh Culinary Herbs

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INTRODUCTION

Culinary herbs and salad greens have always been an important component of the human diet, adding variation and flavor to our staple foods, as well as being used for food preservation. The major commercial form of culinary herbs sold is the dried product, in part because herbs in this form are easy to transport and market, and can be stored for extended periods (42). While fresh herbs are considered more flavorful and superior in quality to dried herbs, they have traditionally been available only from a kitchen garden or from local/regional markets. Widespread commercialization of fresh culinary herbs has been restricted due to high perishability and a relatively short shelf-life.

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In recent years, a marked increase in the demand for a continuous supply of fresh culinary herbs and salad greens has developed (7, 16, 17). This is particularly true in the United States, where the diet has become more diversified by the addition of many ethnic foods. The substitution of herbs in place of salt has also increased their consumption and brought greater visibility to these specialty plants (49).

The result of these market forces has greatly increased interest in the production of fresh herbs and salad greens, for local markets, and for distribution through the major wholesale, retail, and food-service channels (7, 17). Yet marketing of these materials has not, however, been without problems. The relatively small quantities of culinary herbs sold daily means that inventories of the perishable plant materials must be stored for long periods of time (11, 13). In addition, marketing strategies have normally used a uniform handling technology for all types of herbs even though the plants are diverse in botanical origin and physiological characteristics. Postharvest conditions that are adequate for one fresh herb may be entirely inappropriate for others. For example, herb bouquets on sale at retail markets may combine an extremely perishable herb such as chervil (*Anthriscus cerefolium* (L.) Hoffm.) with relatively long lasting herbs such as rosemary (*Rosmarinus officinalis* L.) and thyme (*Thymus* spp.)

Many producers have used technologies such as "in-package" atmospheric modification in attempts to improve shelf-life. Results of these empirical efforts, however, have been inconsistent. Design of innovative packaging as well as the use of conventional postharvest technologies require a better understanding of the biology and other factors involved in the deterioration of fresh herbs. In this review, the physiology of senescence of green tissues and the major factors affecting the postharvest behavior of fresh herbs and specialty salad greens are discussed.

SENESCENCE OF LEAFY TISSUES

Several recent reviews have evaluated the processes involved in senescence of leaves and other plant tissues (39, 54, 56, 57, 58). Under conditions where leafy organs are stressed (high light, drought, high temperature, nutritional imbalances) or cease to produce carbohydrates (low light, tissue harvest), the cells of the leaf commence catabolic processes designed to recover important nutrients for reutilization in other parts of the plants. While different plant species have different patterns of loss of leaf constituents (4, 55); hydrolysis of proteins and disassembly of the chloroplast apparatus are accompanied generally by decreased photosynthetic activity and, frequently, by increases in respiration and in ethylene production. The yellowing leaf loses membrane integrity and the related capacity to maintain ionic balance. Senescing leaves are unable to resist attack by mildly pathogenic microorganisms ubiquitous in the environment.

The mechanisms by which leaf senescence is controlled are not well understood. Exogenous applications of growth regulators have been used as a means of deducing endogenous control mechanisms, but results from these studies are often difficult to interpret (36, 39). For example, the treatment of leaves with ethylene will accelerate yellowing, yet inhibitors of ethylene biosynthesis or action have inconsistent effects on natural senescence (2). Similarly, exogenous application of cytokinins has a spectacular effect in delaying senescence in leaves of many species, but in monocotyledonous plants (plants of the Liliaceae family, for example), gibberellins are more effective in delaying senescence. Abscisic acid (ABA) application commonly accelerates leaf senescence, but this effect may well be mediated through stimulation of ethylene production (43). The effects of cytokinins have been suggested to result from reduced sensitivity to ethylene (34).

A recent examination of leaf senescence using an ethylene-resistant mutant of *Arabidopsis thaliana* indicates that in the dark or light, leaf disks of the mutant plants lost chlorophyll much more slowly than control leaf disks and were unaffected by application of ethylene (a treatment that greatly accelerated chlorophyll loss from leaf disks in control plants) (65). Cytokinin did not affect the rate of yellowing of leaf disks from mutant plants, but greatly reduced the loss of chlorophyll from control disks, even in the presence of ethylene. These observations confirm previous suggestions that cytokinins reduce leaf yellowing by reducing sensitivity to ethylene. Application of ABA stimulated chlorophyll loss both in control and mutant *Arabidopsis* leaf disks, even when the stimulated ethylene biosynthesis was inhibited with amino-oxyacetic acid. The effects of ABA on leaf senescence or stresses which elevate endogenous levels of this hormone therefore appear to be independent of ethylene.

FACTORS AFFECTING THE POSTHARVEST LIFE OF FRESH HERBS

Botany

Factors likely to affect the life of a perishable product may be deduced from taxonomic relationships with other plants and, more importantly, the morphology and physiological state of the harvested product. While most of the economically significant temperate zone culinary herbs are members of either the Lamiaceae (mints, *Mentha* spp.; sages, *Salvia officinalis* L.; basils, *Ocimum basilicum* L.) or the Apiaceae family (parsley, *Petroselinum crispum* (Mill.) Nyman ex A.W. Hill; coriander, *Coriandrum sativum* L.; chervil, *Anthriscus cerefolium* (L.) Hoffm.), many other plant families are also represented (Table 1). Differences in the morphology and physiology of the plant frequently reflect the native habitat of individual plant species. Perennial herbs from xerophytic environments such as rocky slopes in the Eastern Mediterranean (sage, rosemary, thyme) are distinguished by water conserving adaptations (small, waxy-surfaced leaves, pubescent leaves, protected stomates). Salad herbs, which typically derive from mesophytic (arugula, *Eruca sativa* Mill.; mache, *Valerianella locusta* var. *olitoria* L.; mints) or even aquatic (watercress, *Nasturtium officinale* R.Br.) environments have large tender leaves, and many exposed stomates, characteristics that can lead to rapid water loss.

Differences in shelf-life among leafy and floral vegetable cultivars have been documented for many products, including lettuce (*Lactuca sativa* L.), leeks (*Allium ampeloprasum* L.), cabbages (*Brassica oleracea* L.), artichokes *Cynara scolymus* L. (36), and broccoli (*Brassica oleracea* L. var. *botrytis*) (Cantwell, unpublished). Similar variations in postharvest behavior among species and cultivars of fresh herbs would be expected. Different basil species and cultivars have demonstrated differential sensitivity to

Table 1. Fresh Culinary and Salad Herbs.

Family & Scientific Name	Common Name
Asteraceae (Compositae)	
Artemisia dracunculus L.	Tarragon
Apiaceae	
Anethum graveolens L.	Dill
Anthriscus cerefolium L. Hoffm. (Umbelliferae)	Chervil
Coriandrum sativum L.	Cilantro (Chinese parsley, coriander)
Cryptotaenia japonica Hassk.	Mitsuba (Japanese parsley)
Foeniculum vulgare Mill.	Fennel
Petroselinum crispum (Mill.) NYM. ex A.W. Hill	Parsley
Brassicaceae (Cruciferae)	
Eruca vesicaria L. Cav. *subsp. sativa* (Mill) Thell	Arugula (Rocket salad)
Nasturtium officinale R.Br.	Watercress
Chenopodiaceae	
Chenopodium ambrosioides L.	Epazote (Wormseed)
Lamiaceae	
Mentha piperita L.	Peppermint
spicata L.	Spearmint
Ocimum basilicum L.	Basil
Origanum majorana L.	Marjoram
vulgare L.	Oregano
Perilla frutescens (L.) Britton	Perilla (Shiso)
Rosmarinus officinalis L.	Rosemary
Salvia officinalis L.	Sage
Satureja montana L.	Savory
Thymus vulgaris L.	Thyme
Liliaceae	
Allium schoenorasum L.	Chives
tuberosum Rottler	Chinese Chives
Polygonaceae	
Rumex acetosa L.	Sorrel
Valerianaceae	
Valerianella locusta L.	Mache (Corn salad, Lamb's lettuce)

low temperature injury (22), and different mint species have differing rates of water loss (Table 2). Most *Origanum* species and types appear to store best at 0°C, yet some (*Origanum tournefortii* and *Origanum pulchellum*) will tolerate storage at higher temperatures (5 and 10°C) better than others (*Origanum vulgare*, upright, large-leaf and prostrate types) (Cantwell and Reid, unpublished). Differential rates of leaf yellowing have been observed in two species of watercress which had similar postharvest head space volatile profiles (52, 53).

Table 2. Postharvest respiratory activity in sprigs of selected field grown culinary herbs.

	Rate			Q_{10} Value	
Herb	0°C	10°C	20°C	0-10°C	10-20°C
		($\mu l\ CO_2 g^{-1} h^{-1}$)			
Basil	18	37	98	2.0	2.6
Chervil	6	42	94	7.1	2.2
Chives	11	58	300	5.3	5.2
Dill	11	54	180	4.9	3.4
Epazote	16	83	110	5.2	1.3
Mache	6	44	77	7.3	1.8
Marjoram	14	36	-	2.7	-
Mint	10	40	140	4.0	3.5
Mitsuba	6	24	55	4.4	2.3
Oregano	11	53	98	4.8	1.8
Parsley	11	56	123	5.1	2.2
Sage	18	54	87	3.0	1.6
Shiso	12	25	52	2.1	2.1
Tarragon	20	52	130	2.6	2.5
Thyme	19	43	113	2.3	2.6
Mean	13	47	118	3.6	2.5

[1] Measured 3 days after harvest and storage at indicated temperatures. Data of Cantwell and Reid (14) and Cantwell and Reid (unpublished).

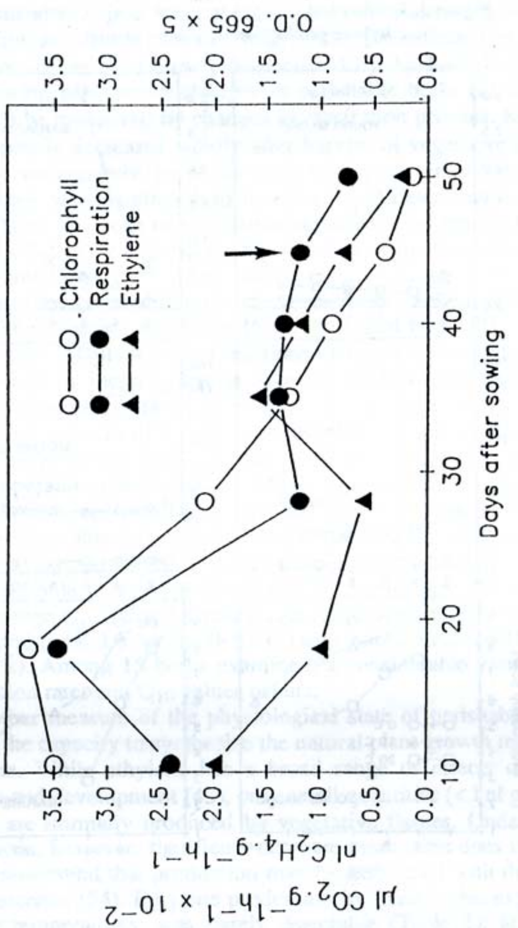
Culture

A considerable body of information regarding the effects of climatic variation and production practices on the yield and essential oil composition of the major culinary herbs is available (12, 23, 24, 50, 51). Environmental factors, including temperature and day length, affect rates of growth (63) and senescence (45, 57) of leafy tissues; agricultural production practices, including fertilization and irrigation regimes, impact the yield, composition, and quality of tissues (19, 32). The relationship of these factors to longevity of the harvested product, either for leafy greens or culinary herbs, is poorly understood, it is likely that variations in postharvest behavior within a given herb species may be partly attributable to differences in the preharvest production environment. Beraha and Kwolek (10) have observed that diseases and other disorders that cause postharvest losses of crisphead lettuce varied with season and growing district. Among the herbs, the shelf-life of California winter-grown oregano (*Origanum* spp.) has been observed to be significantly shorter than that of the summer-grown product. Postharvest browning of winter-grown leaves of this species increased by storage at low temperature (0°C) (Cantwell, unpublished). Similar differences in shelf-life of California-grown cilantro have been associated with seasonal and cultural variations (Cantwell, unpublished).

Development

As marketed, fresh herbs are complex structures which can include stems, leaves, flowers, and, sometimes, roots. Most culinary herbs are harvested as soft or semi-woody leafy stems, but in the case of dill (*Anethum graveolens* (L.) Clarke, C.B.), oregano, and basil, the herb can also include immature or mature flowers. Many salad herbs are harvested as developing leaves (sorrel, *Rumex acetosa* L.; arugula) or intact plants (cilantro, mache), yielding a product that consists of leaves at several different physiological stages. The importance of the leaf development stage on plant metabolism is illustrated by the data of Aharoni and Lieberman (1) on the composition and physiology of harvested pinto bean (*Phaseolus vulgaris* L.) leaves (Figure 1). The relatively high rates of ethylene production and respiration and high chlorophyll content noted in young

Figure 1. Changes in chlorophyll, respiration, and ethylene production associated with plant development.



Measured on the primary leaves of pinto bean plants. The leaves were removed from the plants at different stages of development. Arrow indicates time of leaf abscission. Data from Aharoni and Lieberman (1).

leaves decreases with development. A modest increase in ethylene production is associated with the period of leaf aging prior to leaf abscission. Similar changes in physiology have been observed by Woolhouse (62) for attached shiso (*Perilla frutescens* (L.) Britton) leaves. Photosynthetic activity and chlorophyll content decrease after completion of leaf expansion, and this decrease is followed by an increase in respiration rate prior to leaf abscission.

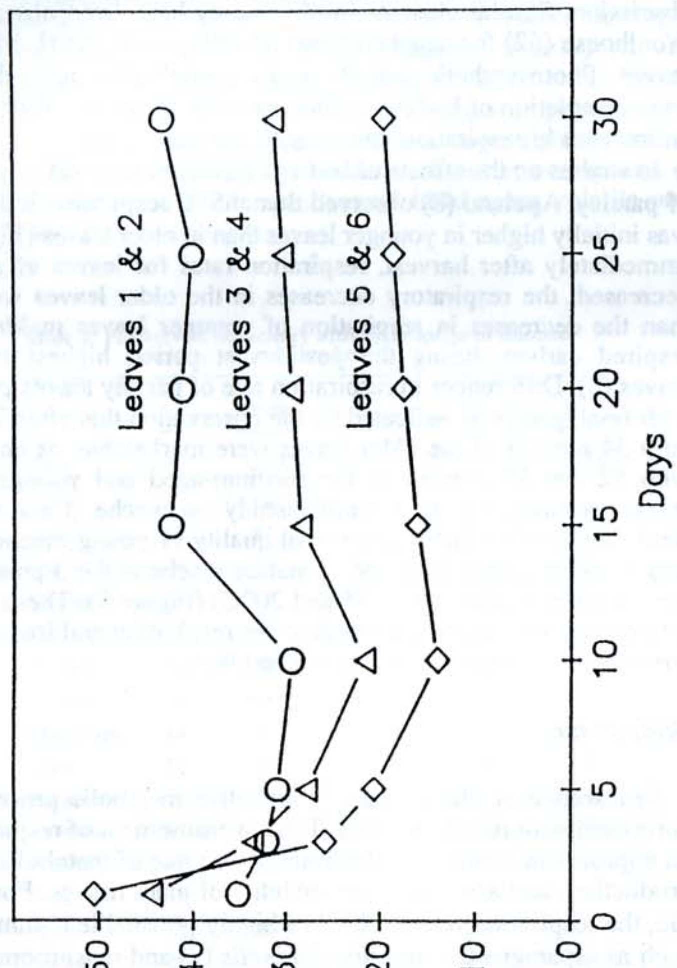
In studies on the effects of leaf age on the postharvest physiology of parsley, Apeland (8) observed that at 5°C respiration in the dark was initially higher in younger leaves than in older leaves (Figure 2). Immediately after harvest, respiration rates for leaves of all ages decreased; the respiratory decreases in the older leaves were less than the decreases in respiration of younger leaves making total respired carbon during the postharvest period highest in older leaves (8). Differences in respiration rate of parsley leaves correlate with final quality as indicated by the observation that after 30 days, only 34 percent of the older leaves were marketable, as compared with 52 and 89 percent of the medium-aged and youngest-aged leaves, respectively. In a similar study on mache (Cantwell and Reid, unpublished data), the visual quality of young mache plants was retained longer than that of mature mache at the 3 postharvest temperatures studied (0°, 10° and 20°C) (Figure 3). These quality differences were associated with lower respiration and lower ethylene production rates by young mache plants.

Temperature

Senescence of plant tissues is an active metabolic process well correlated with respiration rate. Thus, measurement of respiration is an appropriate method for determining the rate of metabolism, heat production, and associated perishability of plant tissues. For example, the respiration rate at 20°C of highly perishable commodities, such as asparagus (*Asparagus officinalis* L.) and mushrooms (*Agaricus bisporus* (J.E. Lange) Imbach [*Agaricus campestris*] of auth., not L. ex Fries) (150 to 200 μl CO_2 $g^{-1}h^{-1}$), is 20 times greater than that of long lasting crops such as onions (*Allium* spp.) and potatoes (*Solanum tuberosum*) (8-12 μl CO_2 $g^{-1}h^{-1}$) (21).

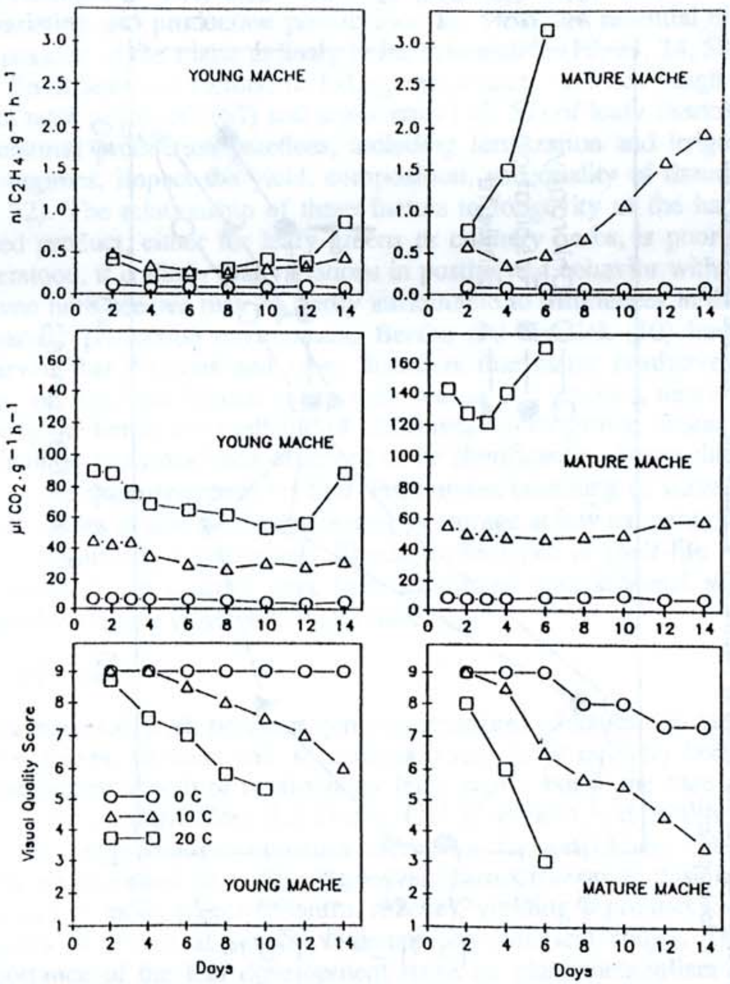
Respiration rates of fresh herbs are relatively high, ranging from

Figure 2. Leaf Development and postharvest respiration rates in parsley. +



Measured on leaves of parsley cv. Bravour stored at 5 °C. Leaves 1 and 2 are the oldest leaves on the plant; leaves 5 and 6 are the youngest leaves on the plant. Data from Apeland (8).

Figure 3. Postharvest changes in visual quality, respiration rates, and ethylene production of mache plants.



Measured on field-grown mache plants harvested at 2 stages of development (young & mature) and maintained in the dark at 0 °C, 10 °C, and 20 °C. The largest leaves of young and mature leaves were 5 and 10 cm^2, respectively. Data of Cantwell and Reid (unpublished).

50 to 300 μl CO_2 $g^{-1}h^{-1}$ at 20°C (Table 2). A relationship between respiration and deterioration of fresh parsley (as indicated by loss of chlorophyll) has been clearly documented by Apeland (8) (Figure 4), allowing postharvest changes in perishable herbs (as in other crops) to be monitored by changes in respiration patterns. Respiration normally decreases rapidly after harvest of vegetative tissues, but may subsequently rise as the tissue undergoes senescence. More rapid rates of respiration lead to more rapid deterioration of the plant tissue. The peak of respiration accompanying senescence has been likened to the "climacteric," which accompanies ripening of many fruits (39).

As in other perishable products, temperature is the most important factor affecting the longevity of harvested herbs (11, 15, 29, 46). The rate of all biological reactions increases as the temperature increases in a manner that is approximated by the van't Hoff rule–an increase in temperature of 10°C increases the rate of the reaction by a factor of 2 to 5 (depending on the temperature range and on the particular reaction or process under study). The values of this temperature coefficient, termed the Q_{10}, tend to be higher for products with high respiration rates and short shelf lives. For example, the Q_{10} value (at 0-10°C) for perishable asparagus and mushrooms is approximately 3, while the Q_{10} value (at 0-10°C) for non-perishable potatoes and onions is approximately 1.5 (21, 46). The average Q_{10} value for respiration among fresh herbs has been calculated to be 3.6 for the 0-10°C range and 2.5 for the 10-20°C (Table 2). Among 15 herbs examined, a considerable variation in respiration rates and Q_{10} values occurs.

Another measure of the physiological state of perishable products is the capacity to synthesize the natural plant growth regulator, ethylene. While ethylene has a broad range of effects on plant growth and development (43), only small quantities (< 1 nl $g^{-1}h^{-1}$ at 20°C) are normally produced by vegetative tissues. Under stress conditions, however, significant ethylene production does occur in such tissues, and that production may be associated with the onset of senescence (54). Ethylene production by fresh herbs, especially at low temperatures, was barely detectable (Table 3); at higher temperatures, ethylene production was markedly higher, although, like other leafy tissues, still comparatively low. The Q_{10} values for

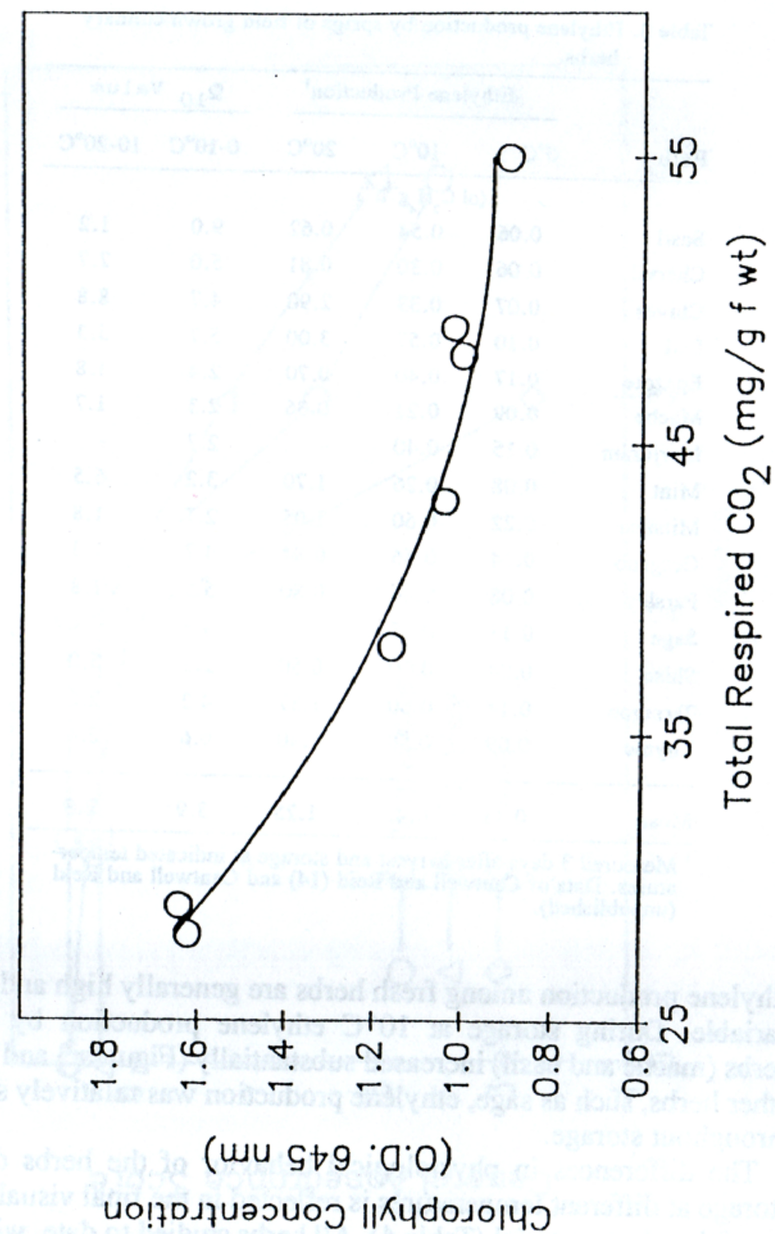


Figure 4. Relationship between chlorophyll content and respiration in stored parsley.

Measured on parsley cv. Bravour. Data from Apeland (8)

Table 3. Ethylene production by sprigs of field grown culinary herbs.

Herb	Ethylene Production[1]			Q_{10} Value	
	0°C	10°C	20°C	0-10°C	10-20°C
	($nl\ C_2H_4 g^{-1}h^{-1}$)				
Basil	0.06	0.54	0.62	9.0	1.2
Chervil	0.06	0.30	0.81	5.0	2.7
Chives	0.07	0.33	2.90	4.7	8.8
Dill	0.10	0.57	3.00	5.7	5.3
Epazote	0.17	0.40	0.70	2.4	1.8
Mache	0.09	0.21	0.36	2.3	1.7
Marjoram	0.15	0.40	-	2.7	-
Mint	0.08	0.26	1.70	3.2	6.5
Mitsuba	0.22	0.60	1.05	2.7	1.8
Oregano	0.14	0.66	0.84	4.7	1.3
Parsley	0.08	0.44	0.80	5.5	1.8
Sage	0.11	0.48	-	4.4	-
Shiso	0.04	0.10	0.50	2.5	5.0
Tarragon	0.14	0.60	1.57	4.3	2.6
Thyme	0.09	0.59	1.40	6.6	2.4
Mean	0.11	0.43	1.25	3.9	2.9

[1] Measured 3 days after harvest and storage at indicated temperatures. Data of Cantwell and Reid (14) and Cantwell and Reid (unpublished).

ethylene production among fresh herbs are generally high and quite variable. During storage at 10°C ethylene production by some herbs (mache and basil) increased substantially (Figures 3 and 8). In other herbs, such as sage, ethylene production was relatively steady throughout storage.

The differences in physiological behavior of the herbs during storage at different temperatures is reflected in the final visual quality of the plant material (Table 4). All herbs studied to date, with the exceptions of basil, shiso, and possibly some types of oreganos, respond most favorably to low temperature storage and maintain

Table 4. Effect of temperature on visual quality of fresh culinary herbs.

Herb	Storage Temperature[1]		
	0°C	10°C	20°C
	(visual quality)		
Basil	2	8	7
Chervil	8	6+	1
Chives	9	6	3
Dill	9	6+	2
Epazote	9	7+	5
Mache	8	5	2
Marjoram	9	8+	1
Mint	9	6+	2
Mitsuba	9	7+	4
Rosemary	9	9	7
Sage	9	8	-
Shiso	6	8+	3
Tarragon	8	6	-
Thyme	9	8	7

[1] Field-grown herbs were harvested and held in containers ventilated with humidified air at the indicated temperatures for ten days. Visual quality scores were based on appearance of herbs with: 9=excellent quality; 7=good quality, minor defects; 5=fair quality, moderate defects, limit of salability; 3=poor quality, major defects; 1=unusable. Data of Cantwell and Reid (unpublished).

+ Herbs with reduced visual quality at 10°C when exposed to 5-10 ppm ethylene.

excellent quality over a period of 10 to 14 days. Under experimental conditions, most fresh herbs can be held up to 4 weeks at 0°C and still have very good visual quality. Studies over a 10 day simulated marketing period indicate many herbs have acceptable quality if stored at 10°C, but herbs kept at ambient temperatures have a greatly reduced shelf-life. Hruschka and Wang (25) demonstrated that watercress, parsley, and mint, top-iced and stored at 0°C, remained in excellent condition for 2 weeks (Figure 5). Mint had a shorter shelf life than parsley or watercress, and after 3 weeks only 25 percent of the mint was saleable after trimming as compared with 45 and 60 percent of the parsley and watercress, respectively.

Some tropical and subtropical commodities are damaged if held below a critical nonfreezing temperature (28, 37). Such low temperature damage, known as chilling injury, may be observed as internal or external discoloration, development of surface lesions, increased susceptibility to decay organisms, and reduced shelf life. This minimum safe temperature for storage may vary for specific products, but is most often in the 8-12°C range. Symptoms often become more apparent once the product has been transferred to a temperature higher than the storage temperature. Among the herbs and salad greens, basil and shiso are currently known to be chilling sensitive. The sensitivity of these 2 herbs to chilling injury presents practical problems, as basil is a major component of most mixed herb and salad green shipments. The lack of temperature compatibility between basil and other herbs usually leads to holding the plants at an intermediate temperature (between 5 and 10°C), which still induces chilling in basil (Figure 6) and substantially increases the rate of deterioration of other herbs.

Hopkirk et al. (22) observed that while the symptoms of chilling injury in basil varied, the most prevalent damage was a brown discoloration of the interveinal areas of the leaf. Stem browning and collapse, root discoloration in seedlings, loss of glossy appearance, wilting of the leaves, and loss of characteristic aroma were also noted as symptoms of exposure to chilling temperatures. The development of chilling injury in tissue stored over time at different temperatures has been documented (22) (Figure 6); chilling severity depends on the period of exposure as well as the specific storage temperature. For example, chilling symptoms sufficient to reduce marketability occur only after more than 9 days at 10°C, but the same reduced quality state is reached after only 5 days at 7.5°C. Dostal (18) has reported that holding basil at 10°C reduced shelf life to 8 days as compared with 12 days maximum shelf life attained at 15°C.

Numerous techniques have been employed to alleviate or mitigate the development of chilling symptoms in fresh products (28, 37).

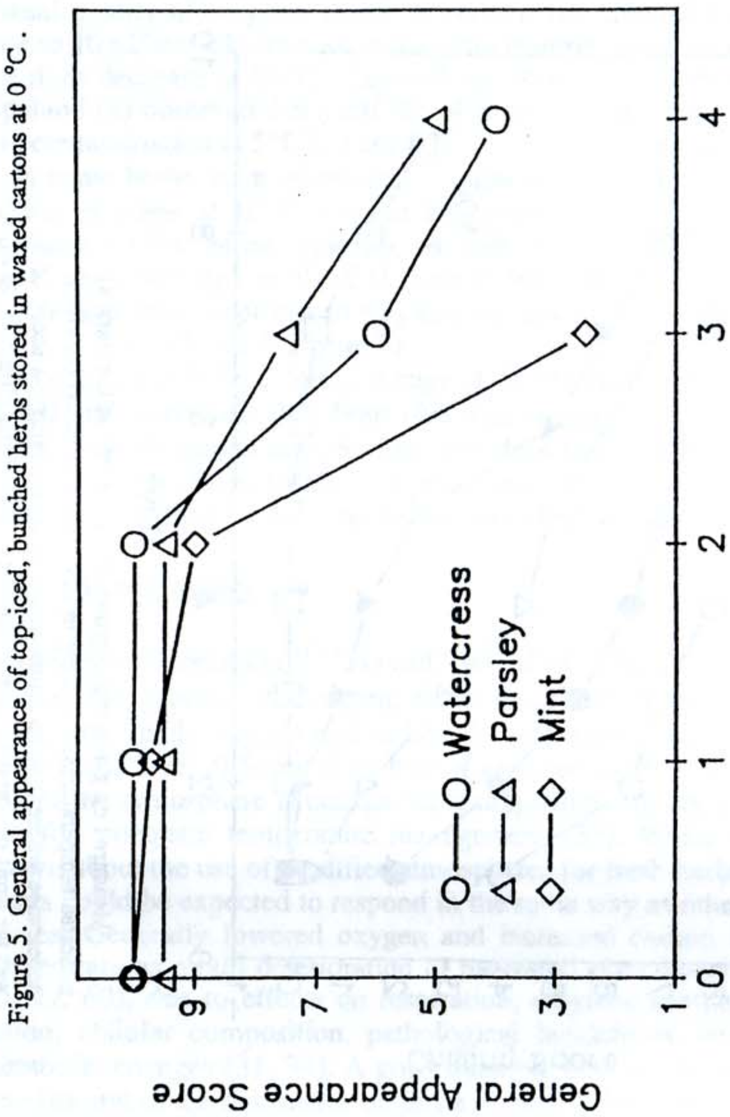
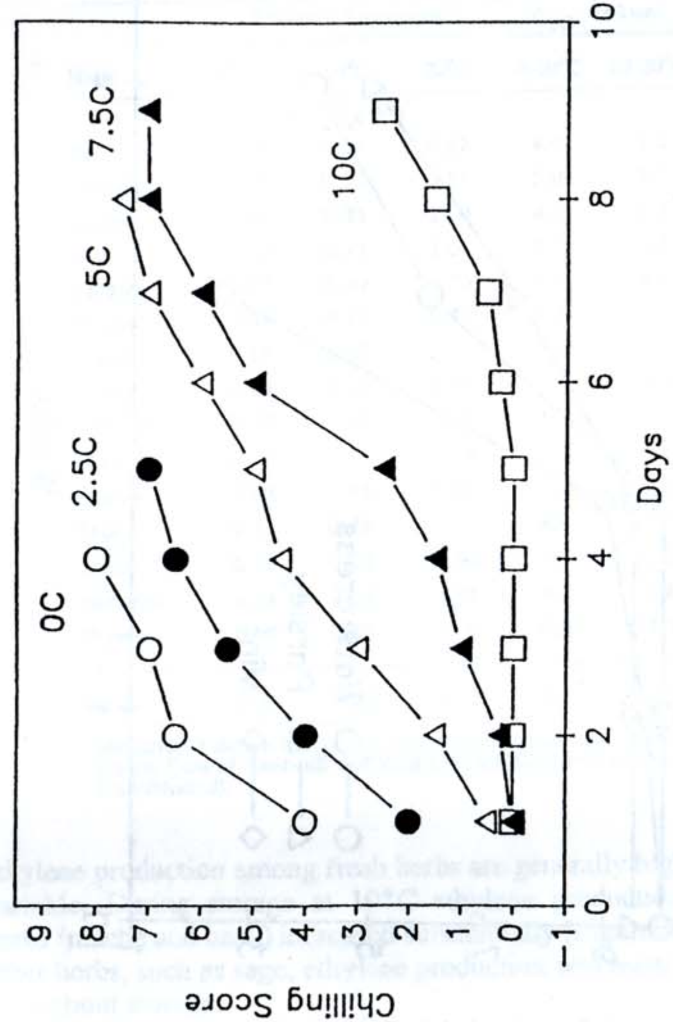


Figure 5. General appearance of top-iced, bunched herbs stored in waxed cartons at 0 °C. Herbs were scored on a visual appearance scale from 10 = excellent to 2 = poor

Figure 6. Development of chilling injury on sweet basil.



Measured on greenhouse-grown sprigs stored in the dark at indicated temperatures. Chilling injury score was based on visual appearance where 0 = no injury and 8 = severe injury; a score of 3 was the limit of commercial acceptability. Data from Hopkirk, *et al.* (22).

Preharvest factors observed to modify the development of chilling symptoms in sweet basil have been age of the leaf tissue and time of day of harvest (18, 22). Young seedlings and multiple-harvested, field-grown basil plants were more susceptible to chilling than sprigs from the first harvest of field-grown plants. Cuttings harvested at the end of the dark period in growth-chamber experiments had more visible chilling injury than tissue harvested after 4 hours of exposure to light (22). Changes in chilling susceptibility of basil may reflect diurnal changes in the carbohydrate status of the tissues as previously demonstrated in tomato seedlings (*Lycopersicon esculentum* Mill.) (35).

Another important factor in the development of chilling injury in basil appears to be the species and cultivar, with common sweet basil being one of the cultivars least sensitive to chilling (22). Sufficient variation in development of chilling symptoms occurred among the 20 cultivars and 3 species, meriting further investigation. Atmospheric modification (1 and 5% O_2; 5 and 16% CO_2) does not appear to reduce chilling injury (Cantwell and Reid, unpublished data). Dostal (18) has also reported that controlled atmospheres failed to ameliorate chilling injury in basil held at 5°C.

The leaf blades of shiso discolored when stored at temperatures below 10°C, but symptoms developed more slowly than those for basil (Cantwell and Reid, unpublished data). In contrast to basil, however, shiso rapidly deteriorated at temperatures above 10°C. Leaf discoloration may also occur in oregano produced under cool weather conditions, although optimum storage temperature for this herb is usually 0°C (14).

Ethylene

Although leafy tissues produce ethylene in trace amounts, sensitivity of this tissue to ethylene contamination in the postharvest environment is very high (30, 41, 44). Most responses to ethylene occur at low concentrations of this gas, the threshold concentration is usually at a concentration of 0.1 to 10 µl/liter, and maximal effects to plant tissue from ethylene are observed between 1 and 10 µl/liter (43, 64). Since the exhaust of a gasoline engine contains more than 500 µl/liter ethylene and storage rooms containing ripening fruits may contain as much as 5000 ppm, the atmosphere in areas where vegetables and herbs are handled (packing sheds, transit vehicles, wholesale warehouses and retail stores) often contain a concentration of more than 1 µl/liter ethylene.

Vegetative tissues respond to ethylene exposure in various ways (43, 64). Commonly observed responses include accelerated leaf yellowing, leaf abscission, and epinasty (downward growth of the leaf and petiole which makes the plant look wilted), undesirable responses that can be observed during postharvest handling of many leafy vegetables. When cut herbs are exposed to different concentrations of ethylene at 20°C and examined periodically, sensitive herbs respond to 0.4 µl/liter C_2H_4; slightly sensitive herbs respond only at 9 µl/liter C_2H_4, and insensitive herbs have no visual response, even at 30 µl/liter C_2H_4. Individual herbs exhibit different visual responses to ethylene (Table 5). Some herbs, including basil and savory (*Satureja* spp.) become epinastic, but yellowing and

Table 5. Effects of ethylene on fresh cut herbs.

Herb[1]	Ethylene Sensitivity	Visual Symptoms		
		Yellowing	Epinasty	Abscission
	(response)	(relative response)		
Basil	++	-	++	-
Marjoram	+++	++	+++	+
Mint	+++	++	++	++
Oregano	++	+	++	-
Parsley	+++	+++	-	-
Rosemary	-	-	-	-
Sage	-	-	-	-
Savory	++	-	++	-
Thyme	+	+	-	-

[1] Fresh cut herbs were exposed to different concentrations of ethylene at room temperature (approximately 22°C) for as long as 7 days. Sensitivity was scored according to severity of the symptoms and the concentration of ethylene required to evoke them using the procedure of Kader (30). Sensitivity to ethylene: - = no response to 30 ppm ethylene; + = response to 30 ppm ethylene; ++ = response to 9 ppm ethylene; +++ = response to 0.4 ppm ethylene. Visual Symptoms: - = none; + = slight; ++ = moderate; +++ = severe.

abscission are usually observed only in the most sensitive species such as parsley, mint and marjoram (*Origanum marjorana* L.). Visual quality of ethylene sensitive herbs is not affected by exposure to 10 µl/liter ethylene when the plant material is stored at 0°C, but does decrease at 10°C (Cantwell and Reid, unpublished data). Apeland (8) observed that shelf life of parsley is affected by ethylene contamination at 5°C but not at 0°C.

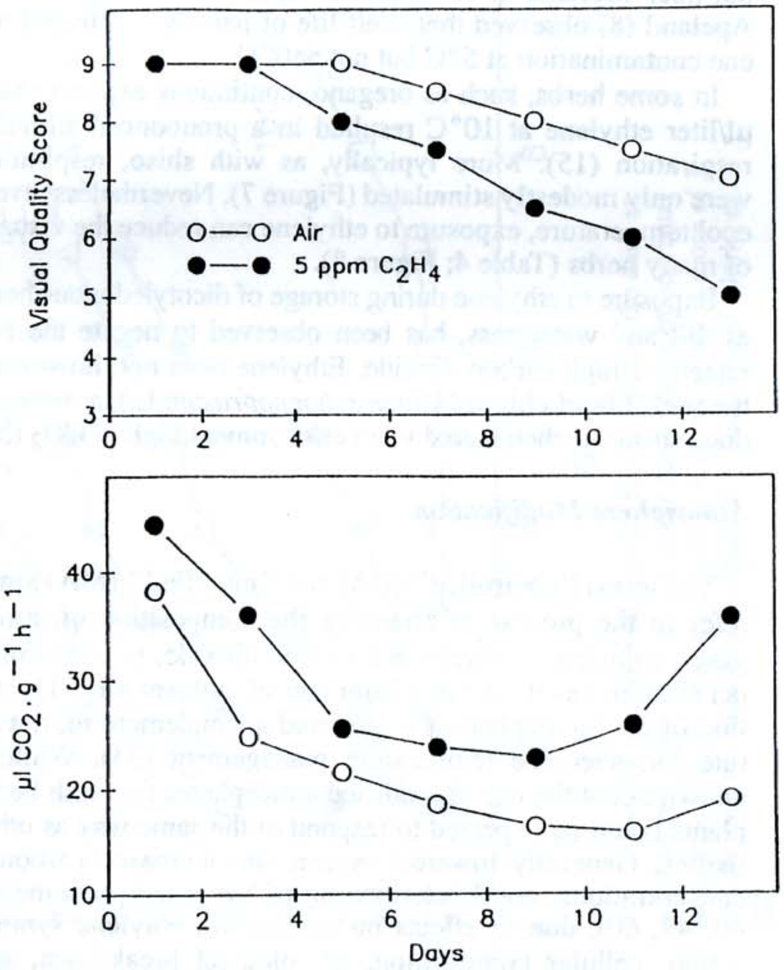
In some herbs, such as oregano, continuous exposure to 5 to 10 µl/liter ethylene at 10°C resulted in a pronounced stimulation of respiration (15). More typically, as with shiso, respiration rates were only modestly stimulated (Figure 7). Nevertheless, even at this cool temperature, exposure to ethylene can reduce the visual quality of many herbs (Table 4; Figure 8).

Exposure to ethylene during storage of dicotyledonous herbs, such as dill and watercress, has been observed to negate the beneficial effects of high carbon dioxide. Ethylene does not, however, reduce the shelf life of chives (*Allium schoenoprasum* L.), a monocotyledonous species, when stored in an environment high in CO_2 (3).

Atmosphere Modification

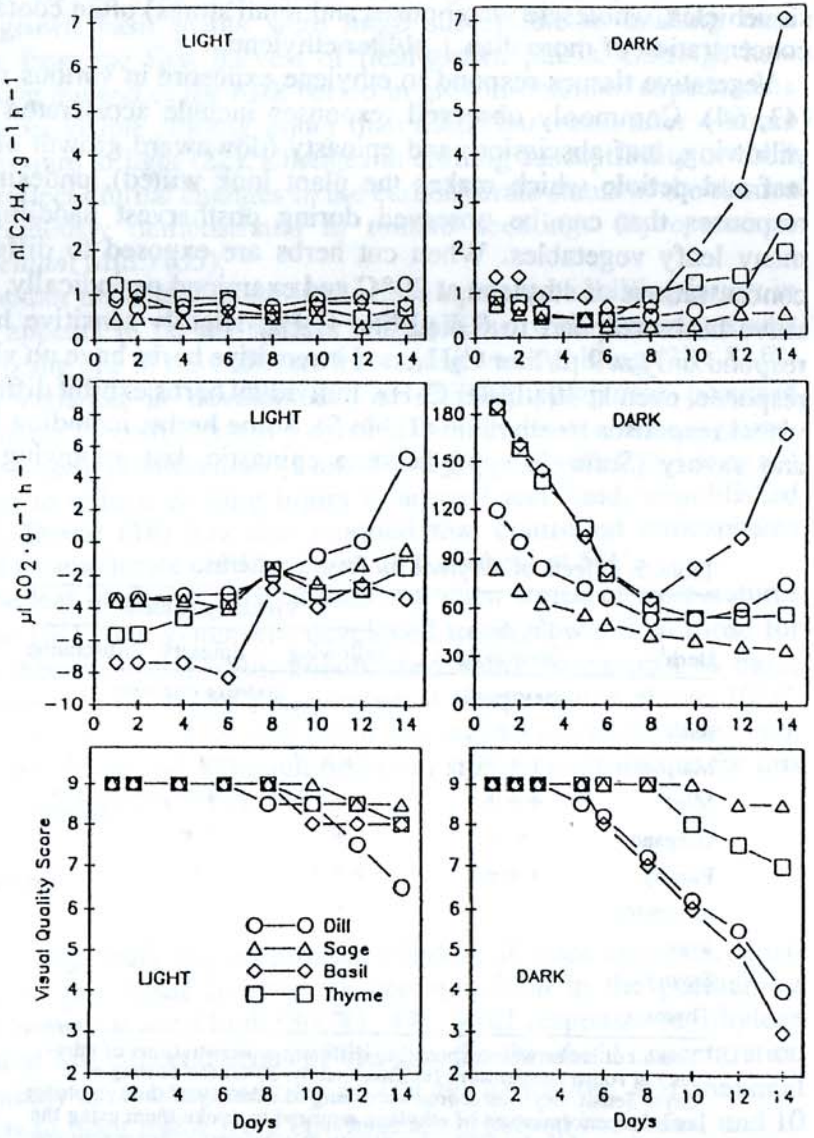
The terms "controlled" (CA) and "modified" (MA) atmosphere refer to the process of changing the composition of atmospheric gases, principally oxygen and carbon dioxide, surrounding a product to some level different from that of ambient air (31). Modification of the atmosphere is considered a supplement to, not a substitute for, adequate temperature management (33). While little is known about the use of modified atmospheres for fresh herbs, these plants could be expected to respond in the same way as other green tissues. Generally lowered oxygen and increased carbon dioxide concentrations retard deterioration of harvested plant material (26, 40, 47, 60), due to effects on respiration, ethylene synthesis and action, cellular composition, pathological breakdown, and other metabolic changes (31, 34). A good example both of the potential benefits and of the detriments of atmosphere modification to visual and sensory quality of green tissues is exhibited by broccoli. Tissue yellowing is greatly retarded by decreasing the oxygen levels, but oxygen concentrations below 0.5 percent can result in tissue anaer-

Figure 7. Postharvest changes in visual quality and respiration rate of Shiso.



Measured on greenhouse-grown sprigs stored in the dark in air or 5 $\mu l/l$ ethylene at 10 °C for the indicated times. Herbs were stored on a visual appearance scale from 9 = excellent to 3 = poor. Data of Cantwell and Reid (unpublished).

Figure 8. Postharvest changes in visual quality, respiration rates, and ethylene production of herbs stored in the light or dark.



Monitored on fresh, intact plants placed in flow systems at 10 °C and light (75 μEinsteins$\cdot m^{-2} sec^{-1}$) or dark for indicated times. Plants were 4 weeks old from day of seeding in greenhouse. Data of Cantwell and Reid (unpublished).

obiosis and development of off-odors (60). Similarly, while high carbon dioxide levels retard yellowing and stem toughening, concentrations of CO_2 above 10 percent during storage at 5°C also result in undesirable off-odors (60).

Apeland (8) observed that lowered atmospheric oxygen levels, alone or in combination with elevated carbon dioxide, reduces color loss in parsley (Table 6). Aharoni et al. (3) have reports that 5 to 10 percent CO_2 from respiration retards yellowing of coriander, dill, chives, and watercress stored in polyethylene lined containers. Ishii and Okubo (27) have maintained the quality of the very perishable Chinese chives (*Allium tuberosum* Rottl. ex K. Spreng.) by packaging bundles in polyethylene bags and storing at 0°C and 10°C. After 3 days, the package atmospheres contained increased carbon dioxide (5% at 0°C and 7% at 10°C) concentrations. Respiration rates were reduced, and chlorophyll, carotene, and ascorbic acid levels were maintained better under modified atmosphere storage conditions at 10°C than at 0°C. No significant differences in visual quality were noted between samples stored in air and MA at 0°C. At higher temperatures (20°C or 30°C), the development of anaerobic conditions results in the development of off-odors unless the bags are perforated to maintain levels of at least 4 percent oxygen in the bags. Dostal (18) reported a 2.5-fold increase in shelf life at 20°C of sweet basil stored in 1.5 percent O_2 and 0 percent CO_2 as compared with storage in air.

Table 6. Effect of modified atmospheres on the quality of parsley.

Atmosphere	Color[1] (scale units)	Marketable (%)
Experiment 1 (75 days storage)		
Air	5.5	36
10.5 % O_2 + 0.5 % CO_2	7.0	68
5.0 % O_2 + 0.5 % CO_2	7.5	75
2.5 % O_2 + 0.5 % CO_2	7.7	80
Experiment 2 (45 days storage)		
Air	5.1	44
10 %O_2 + 11% CO_2	8.3	96
5 %O_2 + 16% CO_2	7.9	93

[1] As determined for parsley cv. Bravour stored at 5°C. Color rated on a hedonic scale where 9 = dark green and; 1 = yellow. The percent of marketable product was based on the proportion of plant material having a color score of 7 to 9. Data of Apeland (8).

Light

Fresh culinary herbs are commonly shipped via air and subsequently placed under lighted retail conditions. Light is generally considered to slow senescence of leafy tissues (36, 54) and the level and quality of light may be expected to modify any effects. Veierskov (59) has demonstrated clearly that senescence of detached leaves in both monocots and dicots depends upon the level of irradiance. If irradiance levels are below the light compensation point for CO_2 fixation (<10 $\mu E \cdot m^{-2}s^{-1}$), leaves senesce, losing protein and chlorophyll in the process. At high irradiances (approximately 80-100 $\mu E \cdot m^{-2}s^{-1}$), chlorophyll declines without any coincident decrease in protein, a response indicative of photo-oxidation. At irradiance levels slightly above the light compensation point (15 $\mu E \cdot m^{-2}s^{-1}$) chlorophyll and protein levels remain stable, and leaves last the longest.

Wittenbach (61) has studied the reversibility of senescence of wheat (*Triticum* spp.) seedlings by exposure to light after different lengths of time in the dark. Seedlings treated with light after being held 2 days in the dark recovered original levels of chlorophyll, protein, and photosynthetic activity. After 4 days in the dark, however, only partial recovery of these factors was possible. Thimann (55) has demonstrated that senescence processes in dicots and monocots may be affected differentially by tissue wounding and manipulation of stomatal aperture.

Preliminary results from light and dark storage experiments with young seedlings indicate some fresh culinary herbs are affected by light (Figure 8). The quality of dill, basil and thyme remain better in light; no difference in visual quality is detected for sage. Herb quality declines before the plants lose the capacity to fix CO_2. In the dark at 10°C, respiration rates decline and subsequently increase during tissue senescence. Initial ethylene production rates are similar for light- and dark-stored herbs. In the dark, a major increase in ethylene production is associated with the final stages of senescence and loss of visual quality.

In experiments emulating commercial handling, (where film packages of fresh herbs are often exposed to light), herbs were stored in the dark or in the light (Figure 9). The visual quality of oregano stored at 10°C in zip-lock bags under light or dark conditions was similar, but the quality of the packaged dill and tarragon (*Artemisia dracunculus* L. [*Artemisia redowskii* Ledeb.]) stored under the same conditions was noticeably reduced under light. Ethylene increases were associated with the deterioration of herbs in both light and dark storage conditions. Accumulated carbon dioxide levels in packages of herbs kept in the light were only a fraction of those kept in the dark, presumably due to photosynthetic carbon dioxide fixation occurring in the light.

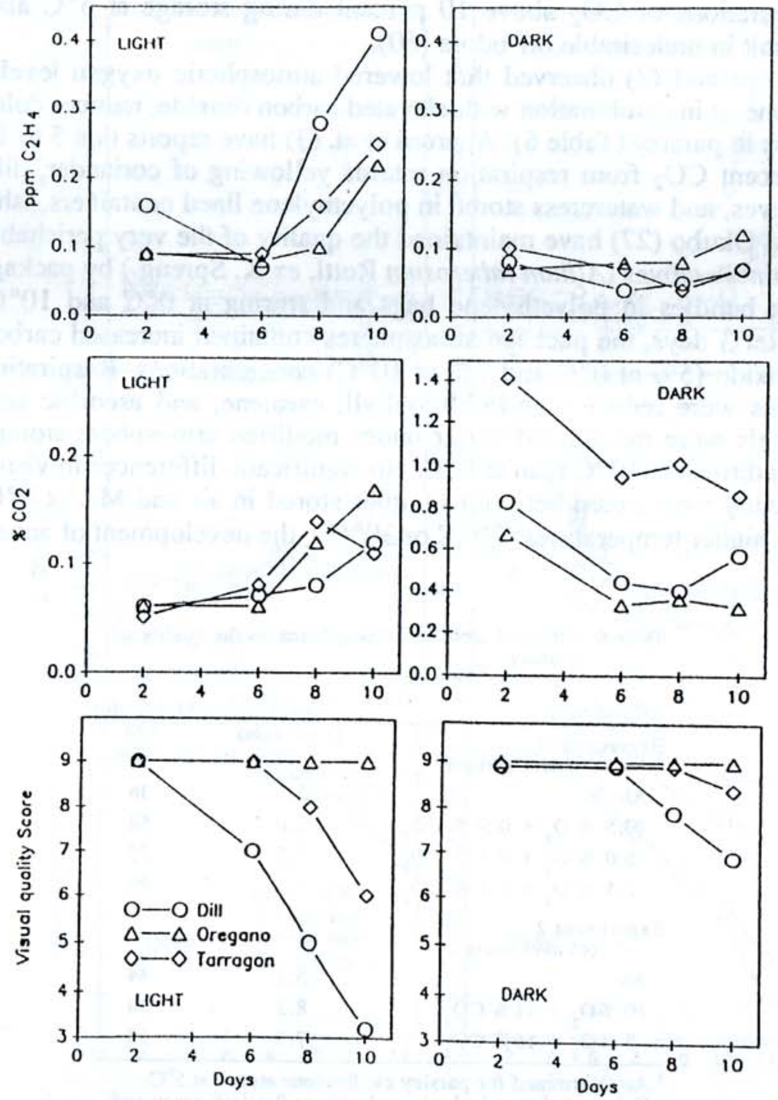
The interplay between carbon dioxide, ethylene, and light in plant senescence is complex. Carbon dioxide is an antagonist of ethylene action and retards ethylene-mediated processes, but may promote ethylene production in some plants (40). Light may stimulate ethylene production under high CO_2 conditions (34). The levels of CO_2 attained and the effects of the interactions among these gases and light on the quality of a packaged plant product are difficult to predict.

One significant problem frequently associated with herbs packaged in plastic films and exposed to lighted conditions (or fluctuating temperatures) is condensation. Maintaining high humidity usually enhances product longevity, but free moisture can favor development of molds and bacteria (20, 33). Different salts and sugar alcohols have recently been demonstrated to be effective in maintaining stable high relative humidity levels in film packages without condensation (48).

Water Loss

Water loss is a major contributor to reduction in quality of fresh leafy products (14, 25), with fresh herbs and salad greens varying in the rate of water loss (Table 7). The high surface to volume ratios and large number of stomata in green leafy tissues result in high rates of water loss through transpiration, which result in loss of marketable weight and visual quality, and may affect the physiology and ability of the product to resist attack by pathogens.

Figure 9. Changes in gas concentrations and visual quality of herbs stored in unperforated polybags.



Measured on field-grown sprigs harvested and stored for indicated times at 10 °C in the light (75 μEinsteins·m^{-2}·sec^{-1}) or dark. Data of Cantwell and Reid (unpublished).

Table 7. Water loss from selected herbs.

Herb	Leaf Area[1]	Rate of Water Loss	
	($cm^2\ g^{-1}$ fr wt)	($ml\ dm^{-2}\ day^{-1}$)	($ml\ g^{-1}\ day^{-1}$)
Basil	23.0	17.0	0.53
Chives	10.7	14.5	0.46
Cilantro	31.8	8.1	1.03
Epazote	22.6	28.2	1.41
Marjoram	24.1	36.0	2.38
Mint			
English	51.5	6.4	3.32
Peppermint	43.3	7.4	2.08
Spearmint	45.0	5.5	1.79
Parsley			
Curly-leafed	21.6	19.6	1.19
Italian	31.4	10.5	0.88
Rosemary	14.2	28.9	1.31
Sage	22.4	42.6	1.28
Tarragon	29.8	10.3	1.65
Thyme			
English	16.7	14.1	3.42
Silver	17.7	18.0	4.75

[1] Approximately 10 g of each herb was placed in a vial with water for 5 h at 22 °C and 60 % relative humidity; each number is the mean of 3 replications. Data of Cantwell and Reid (unpublished).

The amount of water lost before fresh herbs become unsaleable ranges from 5 percent to 40 percent (20). Hruschka and Wang (25) reported visible wilting of watercress, mint, and parsley at 0°C when water loss reached an average of 15, 18, and 20 percent, respectively. Studies on herb quality during storage indicates that chives and thyme are still marketable after losing 25 and 40 percent of the fresh weight, respectively (Table 8). Similar water losses in mint and dill render these items unsaleable because of wilting.

Prevention of water loss has been one of the major objectives of packaging fresh herbs in plastic films for sale at retail outlets (25). Aharoni et al. (3), demonstrated that the quality of numerous salad herbs (watercress, dill, chives, chervil, coriander, and sorrel) stored for 5 days at 6°C followed by 2 days at 12°C was markedly improved by the use of polyethylene-lined cartons. The effectiveness of both perforated and unperforated films for protecting the quality of herbs has been investigated using polyethylene bags containing herbs held dry or standing in water (Table 8 and 9). Polyethylene bags with 2 percent of the surface perforated did not extend the shelf-life of herbs as compared with dry storage, whereas polyethylene bags with no perforations were effective in reducing water and quality losses as reflected by visual quality scores similar to those observed for herbs stored in standing water. In the latter case, the negative water loss data indicated that many herbs were able to absorb more water than losses through transpiration.

Table 8. Quality characteristics of fresh herbs stored in dry or moist conditions.

Herb[1]	Storage Temperature	Quality			Turgidity			Weight Loss		
		Dry	Vented	Water	Dry	Vented	Water	Dry	Vented	Water
	(°C)	(Visual rating[2])			(Visual rating[3])			(%)		
Chives	0	5.7	7.0	7.3	2.0	2.3	3.0	40	21	-19
	10	3.0	2.7	4.8	1.5	1.0	2.5	62	62	8
Dill	0	3.0	3.3	8.0	1.0	1.0	3.0	28	29	-7
	10	1.0	1.0	2.0	1.0	1.0	1.5	73	68	44
Mint	0	3.0	5.7	7.4	1.0	2.0	2.8	34	29	-12
	10	1.3	1.0	6.7	1.0	1.0	2.8	69	68	16
Thyme	0	5.0	4.7	8.0	2.0	2.0	3.0	25	23	-4
	10	1.7	3.0	8.0	1.0	1.0	3.0	63	62	8

[1] Herbs (10-15 g each) were stored in the dark for 2 weeks in either an uncovered 1 liter jar (dry), 1.5 mil polybag with 2 % venting (vented), or with stems immersed daily in fresh tap water contained in a pint jar (water). Values are means of 3 replications. Data of Cantwell and Reid (unpublished).

[2] Visual quality rated on hedonic scale from 9 = excellent to 1 = not usable.

[3] Turgidity rated on hedonic scale from 3 = turgid to 1 = wilted. Relative humidity of 0 °C and 10 °C storage rooms was 80 % and 52 %, respectively.

Table 9. Quality characteristics of fresh herbs stored in dry or nonvented conditions.

Herb[1]	Storage Temperature	Quality			Turgidity			Weight Loss		
		Dry	Vented	Water	Dry	Vented	Water	Dry	Vented	Water
	(°C)	(Visual rating[2])			(Visual rating[3])			(%)		
Chervil	0	-	8.7	9.0	-	2.8	3.0	-	0	-11
	10	-	6.0	6.0	-	2.3	3.0	-	1	-1
Mache	0	-	7.7	8.0	-	2.5	3.0	-	0	-1
	10	-	3.7	4.7	-	2.5	2.8	-	1	2
Mint	0	2.7	8.0	8.0	1.0	2.8	3.0	30	1	-11
	10	1.0	4.0	4.0	1.0	2.0	1.8	86	4	8
Oregano	0	1.3	3.0	2.0	1.0	2.5	2.5	38	1	-5
	10	1.0	4.7	6.0	1.0	2.73	0	82	4	0
Rosemary	0	4.0	8.0	8.0	2.0	2.7	3.0	30	1	-16
	10	1.0	6.7	6.7	1.0	2.5	2.0	70	1	-8
Tarragon	0	2.0	6.7	7.3	1.0	2.5	2.8	33	1	-12
	10	-	-	-	-	-	-	-	-	-

[1] Herbs (10-15 g each) were stored in the dark for 2 weeks in either an uncovered 1 liter jar (dry), 1.5 mil polybag with stapled flap (unvented), or with stems immersed in fresh (daily) tap water contained in a pint jar (water). Values are means of 3 replications. Data of Cantwell and Reid (unpulished).

[2] Visual quality rated on hedonic scale from 9 = excellent to 1 = not usable,

[3] Turgidity rated on hedonic scale from 3 = turgid to 1 = wilted. Relative humidity of 0 °C and 10 °C storage rooms was 80 % and 52 %, respectively.

QUALITY OF HERBS

The ultimate goal in understanding postharvest behavior of herbs is to improve the quality of these products in the marketplace (38). Quality characteristics of fresh culinary herbs are largely visual and

include an appearance of freshness, a uniformity of size, form and color, and the lack of defects such as damaged or yellowed leaves and decay. Kinesthetic quality components such as the firmness or crispness of the leafy tissue are also important, especially for salad greens.

Unlike dried herbs and spices (5, 6), few marketing guidelines or standards of quality for fresh culinary herbs exist. The retention of aroma and flavor in fresh herbs must be considered, but neither legal nor paralegal standards for these compounds in fresh produce have been formulated (9). As with other postharvest aspects of fresh culinary herbs, little research has been conducted on handling techniques that will aid in the retention of essential oils. Preliminary observations have suggested that chilling temperatures appeared to reduce the overall aroma of basil (22). Spence and Tucknott (53) noted that the volatile essential oils of two watercress cultivars, although similar at harvest, began to differ during storage at 10°C. Research on the relationship between volatile oils and postharvest handling is needed to assist in the design and development of packaging materials that prolong the shelf-life of the product and maximize aroma and flavor retention.

SUMMARY

The relative neglect of studies on the senescence of the economically important leafy crops has been noted by Lipton (36). Information on the postharvest physiology of the fresh culinary herbs and salad greens is less than that for the common leafy vegetables. Apart from the use of herbs such as parsley, shiso, and garden nasturtium (*Tropaeolum majus* L. Ann.) as model systems to study photosynthesis and senescence (4, 55, 62), little basic research has been conducted relevant to the physiology and postharvest handling of fresh herbs. The physiological diversity of fresh herbs coupled with the commercial need to develop postharvest handling systems to supply this plant material throughout the year, demonstrate the opportunities and needs for postharvest research on these long neglected but increasingly valuable plants.

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