POSTHARVEST REQUIREMENTS OF LETTUCE TO CONTROL
PHYSIOLOGICAL DISORDERS

Leonard L. Morris, James A. Klaustermeyer, and Adel A. Kader
Department of Vegetable Crops, University of California, Davis

Lettuce is highly perishable relative to many vegetables and fruits. This perishability coupled with its high volume (approx. 50 million cwt) results in more rejected or discounted lettuce shipments in the New York market than for any other crop. Annual claim payments for lettuce by rail carriers are estimated at over $600,000. A USDA study in the New York area during 1967-69 found lettuce losses to average 4.1, 4.6, and 7.1% at wholesale, retail, and consumer levels. These figures would not include losses occurring after retail sale nor would they include losses in terms of consumer acceptance and quality (1).

Since lettuce increases about 10-fold between field and consumer and since these losses occur at destination, it is apparent that these losses are costly. They represent wastage of food and of labor, services, fuel and materials required to harvest, package, transport, and distribute the discarded lettuce.

Reduced losses and improved quality go hand-in-hand and should be the concern of grower, shipper, buyer, retailer, and consumer. The purpose of this paper is to review the causes of deterioration and evaluate the factors that influence it. These remarks are limited largely to the Crisphead type.

QUALITY

Buyer and consumer acceptance depends largely on visual appearance - color, turgidity, size and conformation of the head, and freedom from defects. These defects can be caused by physiological disorders by pathological breakdown and physical damage. These factors are all related.

Compositional changes are not important to consumer acceptance except as water loss affects turgidity and chlorophyll loss determines color. In general, if lettuce looks attractive its taste is acceptable. Lettuce is normally consumed for its taste, texture, appearance, and bulk and not for its food value except that the relatively large bulk eaten does make a significant contribution to vitamin and mineral requirements. The approximate composition of Crisphead lettuce: water 95.0%; carbohydrates 2.3%; protein 0.8%; fat 0.1%; and minerals 0.2%.

CAUSES OF DETERIORATION

Metabolism

The general process of physiological aging (senescence) common to all living tissues is an important factor in lettuce deterioration. Lettuce is living, "breathing," tissue in which oxidative metabolism (respiration) is breaking down stored foods into CO₂ and water. Death and disintegration is the ultimate result. Thus normal metabolism cannot be stopped; it can only be slowed to the point where its results are not serious. Metabolism has indirect effects on deterioration of lettuce - oxygen is consumed and if depleted to a low level this is harmful - CO₂ is produced and if allowed to accumulate can be damaging -
heat is produced and if not continually removed by refrigeration it will, in turn, accelerate the process - ethylene may be produced and this can cause injury.

The respiration rate of lettuce is of intermediate to high intensity when compared with other perishables. It is of the same order of magnitude as cabbage, carrots and cantaloupes; is much higher than low-respiring crops as apples, citrus fruits, grapes, onions, and potatoes; but is lower than crops like broccoli, sweet corn and asparagus. Figure 1 shows the respiration rate of different types of lettuce and the effects of temperature and reduced O$_2$ of the air.

**PHYSIOLOGICAL DISORDERS**

Lettuce is subject to several physiological disorders that develop, or increase, after harvest. Such disorders are commercially important - more so than pathological breakdown. These disorders are commonly confused and their causes often not recognized. Two very useful publications (4) (5) have set forth descriptions, causes, and control; one (4) is very well illustrated.

Following are comments about the more important disorders together with factors affecting them and the more important practical implications.

**Water Loss**

Since lettuce is largely water, this is potentially a very serious cause of deterioration. The rate of loss depends upon the gradient in vapor pressure between the lettuce and the atmosphere and this is a function of commodity temperature, air temperature, air humidity, air movement, and total pressure. Fortunately control of water loss is readily, and usually, attained under commercial conditions by prompt cooling of the commodity, low air temperatures, high relative humidity, and protection by the package.

**Russet Spotting (RS)**

This is probably the most important disorder of lettuce if we consider the complete chain of events between field and consumption. Factors that influence this disorder may be encountered in the field, during handling, in transit, under wholesale and retail conditions, and in the home. Susceptibility of lettuce to RS varies from lot to lot and it is not possible to accurately predict the level of its occurrence even when postharvest factors are known. The preharvest factors affecting RS include: variety, maturity, and season. The postharvest factors include: temperature, ethylene, and composition of the atmosphere (O$_2$ and CO$_2$ levels). RS can occur under conditions of transit; transfer to marketing conditions is not required for symptom development.

**Factors affecting RS**

1. Temperature - Maximum at near 41°F (5°C) - greatly reduced near 32°F (0°C).
2. Ethylene - Clearly implicated - concentrations of 0.1 ppm causes RS at 41°F - exposure of 3 days causes RS and the maximum can occur after about 7 days.
3. Oxygen - the role of low O$_2$ (near 2%) in reducing RS has been reported by others and has been confirmed.
4. Carbon Dioxide - Increased CO$_2$ levels in the atmosphere can inhibit RS.
5. Maturity - Heads of maturity greater than firm (No. 3) are most susceptible.
6. Season - Mid- to late-season harvests in Salinas are more susceptible than earlier harvests. Others have related this to field temperature. RS is often severe with desert-grown lettuce.
7. Lettuce mosaic - not a required factor, may increase disorder.

**Practical implications**

- Avoid maturity beyond firm (No. 3).
- Maintain low temperatures after harvest.
- Low O$_2$, as under modified atmospheres, can reduce RS.
- Increased CO$_2$ is not recommended, because of Brown Stain.
- Avoid exposures to ethylene throughout the marketing period - likely sources include internal combustion engines and commodities such as ripening fruits.
- Avoid mechanical injury since injured tissues produce ethylene.
Rusty-brown Discoloration (RBD)

RBD is specific to 'Climax' lettuce which is the cultivar grown for the winter harvest and is considered to be the most serious market disorder at this season.

Factors affecting RBD

1. Variety - important only on Climax.
2. Lettuce mosaic virus (LMV) and associated internal rib necrosis (IRN) are related to the severity of the disorder. However, commercially important levels of RBD can develop in the absence of LMV. Conversely, if IRN is present at harvest as a symptom of LMV, then RBD can be expected.
3. Maturity - increased head firmness results in greater susceptibility to RBD.
4. Temperature - low temperatures do not control this disorder, in fact, temperatures near 32°F favor its development as compared with 41°F.
5. Severity of RBD increases with time in storage. However, if LMV is present the rate of development increases.
6. Low O₂ (2 to 5%) does not reduce RBD.
7. Increased CO₂ favors RBD symptoms, especially at 41°F.
8. Ethylene at 10 ppm can increase the severity of RBD.

Practical implications

- Plant only LMV-free seed and avoid inoculation during growth.
- Avoid shipping lettuce showing IRN at harvest.
- Ship only fairly firm to firm heads.
- Avoid extended transit or storage especially of mature lettuce.
- No general changes in cooling or temperature management are indicated at this time.
- Modified atmospheres will not control this disorder but accumulation of CO₂ should be avoided.
- Development of varieties to replace Climax would be a solution.

Internal Rib Necrosis (IRN)

This disorder seems to be limited to the Climax variety that is commonly harvested during the winter in the desert areas. This symptom results from field infection of lettuce mosaic virus (LMV). Since Climax lettuce showing this disorder is very prone to develop RBD, lettuce with IRN should not be harvested for shipment. The disorder can be readily detected by making a slanted transverse cut through the base of the midrib near the cut stem.

Factors affecting

1. Affects only Climax variety.
2. Depends on presence of lettuce mosaic (LMV).
3. Postharvest factors have little or no effect.

Practical implications

- Plant only LMV-free seed.
- Avoid shipment of lettuce if IRN is observable at harvest, RBD would be expected.

Brown Stain (BNS)

This postharvest defect results from exposure to CO₂. Although varietal differences in susceptibility have been noted, no commercial variety is known to be immune. Following conditions which have induced the injury a period of 3-4 days at somewhat higher temperatures is required to maximize symptom development.

Factors affecting BNS

1. Variety - varieties differ and Calmar seems to be one of the most susceptible.
2. Carbon dioxide - presence of CO₂ at levels greater than 2% induce injury at low temperatures.
3. Temperature - severity increases as temperature decreases below 41°F.
4. Oxygen - decreased levels of O₂ (2-5%) when present with elevated CO₂ levels increases severity of BNS.
5. Carbon monoxide - presence of carbon monoxide at 1% or greater increases severity when present with low O₂ and increased CO₂.
6. Ethylene - when present with elevated CO₂, ethylene increases severity of BNS.

**Practical implications**

- Brown stain can be especially important with Calmar grown under central coast conditions in California.
- Avoid accumulation of CO₂ during transit by adequate ventilation or by CO₂ absorption - type of package, method of loading and ventilation within cargo space are all factors in CO₂ accumulation.
- Consider possible CO₂ accumulation in regard to tightness of new vehicles.
- Consider BNS in relation to use of modified atmospheres, i.e. levels of O₂ and CO as well as CO₂.
- Expedient cooling during hot weather may decrease subsequent BNS during transit.
- Severity of the disorder can be expected to increase with duration of transit. BNS is a factor only with transcontinental and overseas shipments.
- BNS symptoms increase under marketing conditions (that induce the injury).

**Pink Rib (PR)**

This appears to be a generally occurring symptom of lettuce senescence. It can occur in the field with overmaturity and commonly develops after prolonged storage.

**Factors affecting PR**

1. Temperature - accelerated by warmer transit temperatures, minimized at 32°F.
2. Season - most serious during warmer seasons.
3. Maturity - accelerated by maturity.
4. Oxygen - low O₂ may accelerate disorder.
5. Carbon dioxide - no known effect.

**Practical implications**

- Avoid advanced maturity, especially for long durations of holding.
- Maintain low temperature after harvest.

**Rib Discoloration (RD)**

This unsightly discoloration is often seen at harvest on the outer head leaves at or near the area of maximum curvature. Currently it is considered to be a field disorder. Little is known about the causal agents of this disorder.

**Factors affecting RD**

1. Favored by warm field temps.
2. Accelerated by maturity.

**Practical implications**

- Inspect at harvest and avoid.
- Not caused by nor controllable by postharvest conditions.

**Tipburn**

Characterized by tan to brown wilted margins on the leaves, this is a rather common market disorder of field origin. Conflicting reports exist as to the cause, or causes, but there seems to be rather general agreement that it is increased by high field temperatures and irregular or unfavorable soil-water conditions. It is doubtful that tipburn increases significantly after harvest but its presence at harvest favors serious decay. If tipburn is present, or suspected, then prompt cooling and low transit temperatures are important.

**Low-oxygen Injury**

Injury can result from O₂ levels of 1% and below, the critical level depending on temperature. This factor must be recognized in the use of modified atmospheres and in the use of film wraps or package liners.

**Freezing Injury**

Freezing after harvest usually results in decay and rapid deterioration. It must be avoided. The lowest safe temperature for lettuce tissue is just below 32°F. If slight freezing occurs in the field, harvest must be delayed until complete thawing occurs.
PATHOLOGICAL DISEASES

Several market diseases occur with lettuce but usually follow general senescence, physical damage, or certain physiological disorders—especially tipburn or freezing. Thus if the lettuce is free of disease at harvest and is handled in such a way as to minimize physical injury and general senescence then the importance of pathological breakdown is greatly reduced.

Several field diseases result in unmarketable heads at harvest time and these heads do not enter the marketing channel. Other diseases are readily detected at harvest and are avoided. Diseases of lettuce are well described and discussed in two publications, (2) and (7).

To reduce losses attributable to pathological disease: avoid shipment when disease is present; remove infected wrapper leaves; avoid lettuce with tipburn; minimize physical damage; cool promptly and transport at near 32°F; use controlled atmospheres during long-distance shipments.

PHYSICAL DAMAGE

The succulence and high water content of lettuce render it susceptible to physical damage at all steps between harvest and destination. Such damage can result in the discarding of lettuce, in reduced appearance, in discoloration, and in increased decay. Furthermore, injured tissue produces ethylene and it respires at elevated levels—both factors favor deterioration. Careful handling is required at all steps. The development of alternative methods of handling requires consideration of the susceptibility of lettuce to physical damage.

REQUIREMENTS AND RESPONSES

Temperature

As with other leafy cool-season vegetables, lettuce should be held at near 32°F. Freezing should be avoided; hence a temperature of 34°F ± 2°F is recommended in order to have some margin of safety.

The rate of lettuce respiration increases greatly as temperature increases, Fig. 1. Likewise, the velocity of deterioration increases 2- to 3-fold for each increase of 18°F (10°C). The relative rates of deterioration compared with that at 32°F are shown in Fig. 2. Thus it can be seen that a delay of 1 hour in the field on a hot day could result in as much deterioration as would occur during 10 or more hours at an optimum storage temperature.

Temperatures near 32°F are especially important if the lettuce is prone to decay as a result of tipburn or physical damage. The effect of ethylene in causing russet spotting is reduced by temperatures near 32°F as compared with 41°F. Although the disorders of 'brown stain' and 'rusty-brown discoloration' are reduced at 41°F compared with 32°F, the higher temperature is not recommended. The better solution for each lies in removal or avoidance of the cause. The establishment and maintenance of desirable temperatures between grower and consumer is the key to the control of most forms of lettuce deterioration.

Relative Humidity

A relative humidity of 95%, or higher, is recommended to control water loss. It appears doubtful that the high humidity contributes to decay. The restriction of air movement by the package, the presence of wrapper leaves, and the use of film wraps all contribute to a desirably high humidity around the head. The potential for serious water loss should be kept in mind in regard to both current and alternative handling systems.

Composition of Atmosphere

Oxygen

Levels of 2 to 5% will reduce respiration rate, Fig. 1, and tend to retard some forms of deterioration. However the use of low O₂ levels is not
a "cure-all" and good temperature management is just as important under modified atmospheres as under air. Injury from very low O₂ levels is discussed above. The requirement to provide a continual supply of some O₂ to the lettuce must be considered in regard to package design, tightness of vehicle, and use of modified atmospheres (see Fig. 3).

Carbon dioxide

Increased levels of CO₂ can cause various injuries - the most common being brown stain, as discussed above. The level of CO₂ should be as low as possible (near 0%). All packaging, handling and transport systems should be designed and operated with this requirement in mind.

Ethylene

Trace amounts (.1 ppm or below) of this gas can result in serious russet spotting. It also tends to enhance other symptoms of lettuce deterioration. Exposure to ethylene should be avoided at all times. Ethylene is a commonly occurring pollutant of the atmosphere. Possible sources to consider include: internal-combustion engines, such as fork-lifts, autos, and trucks; ripening fruits; and the lettuce itself. Exposure can occur almost anywhere in the distribution chain and the consumer's home refrigerator is a prime suspect. The necessity to exclude or remove ethylene must be considered under all handling systems.

SUMMARY

The condition of lettuce in the salad bowl is dependent upon both inherent and environmental factors and thus reflects the actions of grower, shipper, carrier, wholesale distributor, retailer and consumer. Abuses or mistakes at the production end can make subsequent good handling of little benefit. Conversely, sound high quality lettuce will deteriorate rapidly if subsequent handling is poor. Poor quality at destination may not be attributable to one cause but is likely to result from the additive effects of abuses and stresses inflicted all along the distribution channel.

It is becoming increasingly apparent that handling procedures should be evaluated in terms of costs and losses at destination. The physical and physiological requirement of the living (and deteriorating) lettuce must be given first consideration in the use or design of handling systems.

References*


*Selected general references used, or cited, in this paper. Each contains citations to research work with lettuce.
Fig. 1. Comparative respiration rates of Crisphead lettuce and other types as influenced by temperature. Note, also, the effect of lowered O\(_2\) level.

Fig. 2. Relative rates of visual deterioration as established by holding temperature.

Fig. 3. Carbon dioxide accumulation and oxygen depletion in lettuce cartons as a result of restricted ventilation of the space surrounding the carton. The "X" flow was 30 liters of air/hr for a 50-lb carton.