# CHILLING INJURY OF HORTICULTURAL CROPS: AN OVERVIEW

**L. L. Morris**
*Department of Vegetable Crops*
*University of California, Davis, CA 95616*

Most, if not all, horticultural fruits, vegetables, and ornamentals of tropical origin are subject to physiological injury when subjected to temperatures below about 12.5°C but above their freezing temperature. This damage does not involve freezing and is commonly termed *chilling injury*. Chilling-sensitive plants, and plant parts, are subject to injury at all stages of their development, except in the dry-seed stage.

Sensitivity to chilling can limit where, geographically, the crop is grown—especially for perennials—and it can limit when and how annual crops are produced. It can influence germination and establishment of stand, plant growth, length of growing season, the temperature required under protective structures, the storage or holding temperature, the duration of the storage period and the quality of the commodity when marketed.

Although the emphasis in this symposium will be on harvested commodities, many of the points discussed have application to the plant. In fact, one of the papers will focus on germinating seeds and seedlings. Chilling injury can occur in the field, during transportation, during storage, during wholesale distribution, in the retail store, and in the home refrigerator. Therefore, the recognition and the understanding of the phenomenon of chilling injury are of concern to all segments of the industry from grower to consumer. Hence, chilling injury is an interesting and important subject of research for horticulturists who are interested in growth or in postharvest physiology and technology. Furthermore, horticulturists concerned with crop improvement and crop adaptation are interested in the possibility of exploiting sources of resistance to chilling injury to broaden or improve the tolerance of crops to low temperatures. It is known that genetic variability in relation to chilling sensitivity exists within some species. This applies to both growing plants and to harvested commodities. The possibility of utilizing lower growing temperatures under protective structures, or of expanding production into marginal areas, takes on added significance in light of current food and energy considerations.

The above comments relate primarily to crops of tropical origin. However, certain horticultural crops of temperate zone origin also show physiological breakdown after holding at low, but non-freezing, temperatures. There may be some disagreement as to whether or not this type of injury is strictly comparable to classical chilling injury as exhibited by tropical plants. The symposium also will deal with the differences and the similarities between temperate and tropical crops in regard to their temperature sensitivity and their physiological and metabolic responses.

The term "chilling injury" is often used to refer to either the physiological phenomenon, *per se,* or to the resulting symptoms, or to both. Synonymous terms include: chilling damage, chilling disorders, low-temperature injury, low-temperature breakdown, low-temperature disorders, and others. It is useful to recognize distinct phases in regard to the responses and the symptoms that result from chilling exposure. First, there is the primary response to temperature, usually considered to be physical in nature, such as membrane alterations. Secondly, physiological changes occur that, continued over a period of time, can be harmful and can result in the development of symptoms that we then attribute to exposure to low temperatures. It is attractive to think in terms of alleviating the harmful changes or suppressing the development of the resulting symptoms. The last paper will develop ideas in this area.

## Symptoms

The symptoms that develop following chilling exposures are not unique to this stress. However, there are several symptoms that commonly result from chilling and they are often indicative of the severity of the injury. Their development can be retarded by the same low temperature that has brought about the physiological dysfunction. The symptoms often become increasingly apparent after transfer to non-chilling temperatures. The various contributors will discuss the symptoms of specific commodities, but it may be useful for us to first consider, in a general way, some of the more commonly occurring visual symptoms listed below. It is the development of these symptoms that translates into postharvest losses.

1. Surface lesions—pitting, large sunken areas, and discoloration. Development of the symptom of pitting shows the important relationships that exist among the factors of commodity characteristics, the presence of mechanical damage, severity of chilling treatment, and the relative humidity of the atmosphere.
2. Water-soaking of tissues—this disruption of cell structure and accompanying release of substrates must favor the growth of microorganisms. This is a commonly occurring symptom in leaves and is followed by wilting and desiccation.
3. Internal discoloration (browning) of pulp, vascular strands, and seeds.
4. Breakdown of tissues.
5. Failure of fruits to ripen in the expected pattern following removal to ripening conditions.
6. An accelerated rate of senescence, but with an otherwise normal appearance.
7. Increased susceptibility to decay, especially to organisms not usually found growing on healthy tissue.
8. A shortened storage life or shelf life due to one or more of the above responses.
9. Compositional changes—especially in relation to flavor and taste.
10. Loss of growth (sprouting) capacity—especially important with stored propagules.

## Physiological responses

The physiological and biochemical responses of many commodities to chilling temperatures is an active area of research. Confusion and controversy exist as to whether some of these changes represent 1) the primary response to temperature, or whether 2) they are part of the dysfunction that results from the initial event, or whether 3) they are simply secondary symptoms caused by the dysfunction. The responses receiving attention include: changes in membrane structure and function; cessation of protoplasmic streaming; alterations in respiration rates and patterns; changes in ethylene synthesis; and many biochemical and compositional changes.

## Reduction of chilling injury

Studies have been directed toward treatments designed to alleviate chilling injury and the symptoms resulting from this injury. Some treatments have been applied directly to the commodity and others involve manipulation of the environment. The following paper will give us specific examples of success, and lack of success, with certain commodities. Treatments that have shown promise include conditioning at near chilling temperatures before chilling, intermittent warming treatments during chilling, increased $CO_2$ in the atmosphere during chilling, pre-treatments with calcium, pre-treatment with ethylene, and holding under hypobaric conditions during chilling. There is also some indication that membranes can be modified to tolerate chilling better.

At the present time, the problem of chilling injury to harvested commodities can be solved best by simply avoiding exposure to harmful temperatures. This may involve protecting the commodity against a chilling ambient temperature, or it may involve use of desirable warmer controlled temperatures. Proper decisions require information about the relative susceptibility of the commodity, knowledge of threshold chilling temperatures, duration of exposure that can be tolerated, and the effect of other factors, such as fumigation for insect control, that would influence susceptibility. The fact that low transit temperatures are not desirable for chilling sensitive commodities is fortunate from an energy-saving standpoint.

**Some comments on vegetables**

Since chilling injury of vegetables is not one of the specific topics covered in the symposium, I wish to make a few comments. The fact that many vegetables are susceptible to chilling injury has resulted in serious problems and losses in their handling. This relates especially to tomatoes, where the industry has recently mounted a program intended to inform both members of the trade and consumers concerning the proper temperatures for tomatoes. Tomatoes offer a good example of where field chilling, transit chilling, market chilling, and the home refrigerator all contribute to the potential losses of product and quality. All of the "warm-season" vegetables, except sweet corn, are subject to chilling injury. These warm-season vegetables are of tropical origin and all, except sweet potatoes, are fruits (in a botanical sense). In contrast, the cool season vegetables should be stored near 0°C. Asparagus and potatoes are exceptions.

**Retrospect and prospect**

An awareness that certain plants will not tolerate low temperatures has existed for many years. However, widespread interest in chilling injury research has occurred only during the past 30 years or so, and much of the work has taken place in the past 10 to 15 years. Perhaps my own introduction to this subject will give some focus. During the winter of 1937–38, I was a graduate student at Cornell University and my attention was called to a surface breakdown on greenhouse cucumbers shipped by truck from the Midwest to eastern markets. Inspectors certified the cucumbers to have been frozen and claims were filed against the trucker. This was of special interest to me since the trucking company involved belonged to my family. Preliminary investigations indicated that the injury was due to low, but non-freezing temperatures. However, it was evident that very little was known about the disorder. The problem became the subject of my Master's thesis and I have retained a general interest in chilling injury since that time. It is my opinion that 40 years ago the commercial horticulturists were more aware of the occurrence and importance of chilling injury than were horticultural scientists. Only during the past few years has the topic of chilling injury appeared in textbooks of plant physiology.

I am sure that interest in chilling injury will be maintained and that interesting and valuable results will be forthcoming. It is probably safe to predict that chilling injury will assume an importance not previously known in the developing countries as these countries adopt technologies of temperature control and attempt to develop their export markets. The necessity to meet quarantine requirements to move horticultural products from areas of insect infestation will place a new focus on chilling injury. The fumigation treatment may require a subsequent storage period at chilling temperatures. Since these stresses are additive, the implications are obvious. Alternative treatments may require a prolonged holding period in the chilling range. Descriptive research is needed to evaluate the tolerance of cold sensitive crops to various accepted quarantine procedures.

**A positive note**

Chilling injury is not necessarily all bad. We need to be alert to the possibilities of using to our advantage the alterations induced in the commodity by chilling temperatures. For example, slight chilling can result in improved sweetness and texture of stored sweet potatoes. A cold treatment improves the ripening of harvested pears. Night temperatures in the chilling range results in improved color of oranges. There are probably other examples where responses to chilling temperatures can be beneficial.

---

# CHILLING INJURY OF CROPS OF TROPICAL AND SUBTROPICAL ORIGIN

**H. Melvin Couey**
*Agricultural Research Service, U.S. Department of Agriculture, Hilo, HI 96720*

Information regarding chilling injury (CI) of tropical fruits may be found in recent texts and reviews (36, 27, 28). However, there is much additional information in widely scattered sources.[1]

Sensitivity to low temperature is a common property of living systems. Higher animals have elaborate temperature control systems and are damaged if the body temperature remains more than a few degrees below the optimum for any extended period. Many bacteria and fungi thrive only in a narrow temperature range (37). Fruit flies cannot survive more than a few days at less than 10°C and many algae are similar to higher plants in susceptibility to CI.

As in other stress conditions, some plants react temporarily to an abrupt lowering of temperature but have the capacity to recover and to protect themselves against its effects. Other plants or plant parts lack this capacity and are rapidly and apparently irreversibly damaged by even short exposure to chilling temperature. Most likely, only plants exposed to chilling temperature regularly and over evolutionary time select the structures or functions that protect against low-temperature stress. The protective systems utilized may turn out to be either constitutive or adaptive and may differ in plants of different origin. In tropical and subtropical plants, we might anticipate that chilling resistance might be either completely lacking or adaptive. It is probable that the overall sensitivity of the plant is reflected in the sensitivity of the fruit to chilling injury.

My primary interest is in the horticultural aspects of CI. Throughout the recent research relating CI to membrane dysfunction, there is little work relating the insights developed from that very excellent research to the horticultural problem of what can we do to alleviate chilling injury (28). Indeed, the only message I have discerned from this work is that the dysfunction is so deep-seated and so fundamental, that any search for ways to alleviate CI is probably doomed to failure. This may be true, but it is also apparent that a few hard researchers have not received that message and continue to study the environmental and biological factors which influence the development of CI.

Although CI is easily avoided in tropical fruits, there are reasons why low-temperature storage may be desirable. Low-temperature refrigeration is the most manageable way to control fruit ripening and thus may lead to exposure of CI-sensitive fruit to damaging temperatures. Postharvest fungus diseases such as *Rhizopus* may be controlled by low-temperature storage. Quarantine insect pests, such as fruit flies *(Ceratitis, Dacus, Anastrepha),* also may be controlled by low temperature. Obviously, CI severely limits these uses of refrigeration.

There are several ways to limit or reduce sensitivity to CI, some of which have rather broad application, while others are limited to certain fruits. Temperature and exposure time are the prime variables. For any fruit, at any temperature down to freezing, there seems to be some minimum time to induce irreversible injury. This time varies from a few hours to several weeks depending on the fruit and the temperature. In similar fashion, maximum temperatures depend upon the exposure time. If the cold period is interrupted, damage

[1]My thanks to Hilary Burton, Technical Information Specialist, ARS, USDA, for assistance in the literature survey.