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INTERACTION OF WAXES AND TEMPERATURE IN RETARDING MOISTURE LOSS FROM AND CHILLING INJURY OF CUCUMBER FRUIT DURING STORAGE

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Abstract. **The postharvest life of cucumber fruit is extended by various waxes, coatings, and refrigerated transit and storage. Experiments were conducted during the 1994 spring harvest season to determine the effectiveness of five types of fruit and vegetable waxes in retarding moisture loss from and chilling injury (CI) of cucumber fruit stored at 5°C and 15°C. Vapor pressure deficits (VPD's) were approximately the same at both storage temperatures. The effectiveness of the waxes in retarding moisture loss and reducing CI decreased with increasing wax dilution except for the surfactant-based waxes which increased moisture loss and CI at the lowest dilution. A significant interaction was observed between waxes and storage temperature. At low temperatures cracks may occur in some of the waxes which enhance moisture loss from the fruit.**

Cucumbers (*Cucumis sativus* L.) are harvested as unripe fruit. They shrivel, particularly at the blossom end, unless they are stored at high relative humidity. Harvested cucumbers ripen and mature rapidly when they are stored at temperatures above 10°C. The seeds of the mature fruit have hard seed coats making the fruit undesirable for consumption. Yellowing of the fruit occurs rapidly at storage temperatures above 15°C (Debney et al., 1980).

Harvested cucumbers usually are stored at temperatures below 10°C to retard maturation and reduce moisture loss, but they are susceptible to chilling injury (CI) at these temperatures. Chilling injury in cucumbers is first visually observed as a sinking of the spines, followed by surface pittings and dark-colored watery areas on the peel. Within a few days the pitted or sunken necrotic areas are invaded by pathogenic organisms (Morris and Platenius, 1939). Symptoms not visible during low temperature storage develop rapidly when the fruit are removed to warm temperatures. Storage at high relative humidities reduces the severity of CI (Morris and Platenius, 1939). Moisture loss during 5°C storage of 64 PI lines was correlated with development of CI symptoms in the fruit after removal from chilling temperatures (Purvis, 1994). The causal relationship between moisture loss at low temperature and CI symptom development is not known, because the precise mechanism of CI has not been established.

Waxes and other coatings are applied to fresh fruits and vegetables to retard moisture loss and extend the postharvest life. Other benefits, such as improved appearance, reduced CI and lowered respiration rates, may be derived from waxes and coatings. Permeability to water vapor, oxygen, carbon dioxide and ethylene differ for commercial waxes and coatings depending on the various natural and synthetic compounds they contain (Hagenmaier and Shaw, 1992). The objective of this study was to determine the effectiveness of some commercial waxes in reducing moisture loss and CI of cucumber fruit stored at chilling and non-chilling temperatures.

Materials and Methods

Greenhouse-grown Poinsett 76 cucumber seedlings were transplanted to the field in early spring and grown according to standard commercial practices. Fruit were harvested at the slicing stage, randomly sorted into lots for treatment and weighed individually. Five waxes were applied at two or three dilutions. These were: surfactant-based waxes (A and B), a carnauba-based wax (C), a natural products wax (D), and a polyethylene emulsion wax (E). Wax A was diluted 1:10, 1:20, and 1:30; wax B was diluted 1:5, 1:10, and 1:15; wax C was used full strength and diluted to half strength; wax D was diluted 1:10, 1:15, and 1:20; and wax E was diluted 1:10, 1:15, and 1:20. All were diluted with water and applied to individual fruit by gently rubbing approximately 1 ml of the wax over the surface of each fruit with latex gloved hands. The amount was sufficient to provide for some runoff. Unwaxed fruit served as controls. Fruit were air dried for two hours before they were placed in temperature controlled rooms for seven days (Expt. 1) or five days (Expt. 2) at 5°C and 65% RH (approx. 3.0 Pa VPD) or at 15°C and 85% RH (approx. 2.3 Pa VPD). The fruit were weighed daily. After seven (Expt. 1) or five days (Expt. 2) the fruit were removed from 5°C and stored at 15°C for two additional days when they were examined for visible manifestations of CI. Chilling injury was scored on a scale of 1 to 5 with 1 = no injury, 2 = ≥1≤10% of the surface pitted, 3 = ≥11≤25% of the surface pitted, 4 = ≥26≤50% of the surface pitted, and 5 = >50% of the surface pitted. Data were analyzed using SAS Statistics (SAS Institute, 1988).

Results and Discussion

In Expt. 1, fruit waxed with the surfactant-based waxes (A and B) at all dilutions lost more moisture than unwaxed fruit during storage at 5°C (Fig. 1). Fruit that were waxed with the

Table 1. Chilling injury index of Poinsett 76 cucumber fruit stored for seven days (Expt. 1) or five days (Expt. 2) at 5°C followed by two days at 15°C.

Coating[y]	Number of fruit/treatment	Chilling injury index[z] Expt. 1	Chilling injury index[z] Expt. 2
Uncoated	5	4.8 a	2.2 c
A	15	4.8 a	4.6 a
B	15	5.0 a	3.4 b
C	10	3.4 b	2.0 c
D	15	3.4 b	1.6 cd
E	15	2.8 b	1.3 d

[z]Values are means of all concentrations for each wax. Mean separation in columns by Waller-Duncan, 5% level.
[y]Base composition and concentrations of waxes are given in text.

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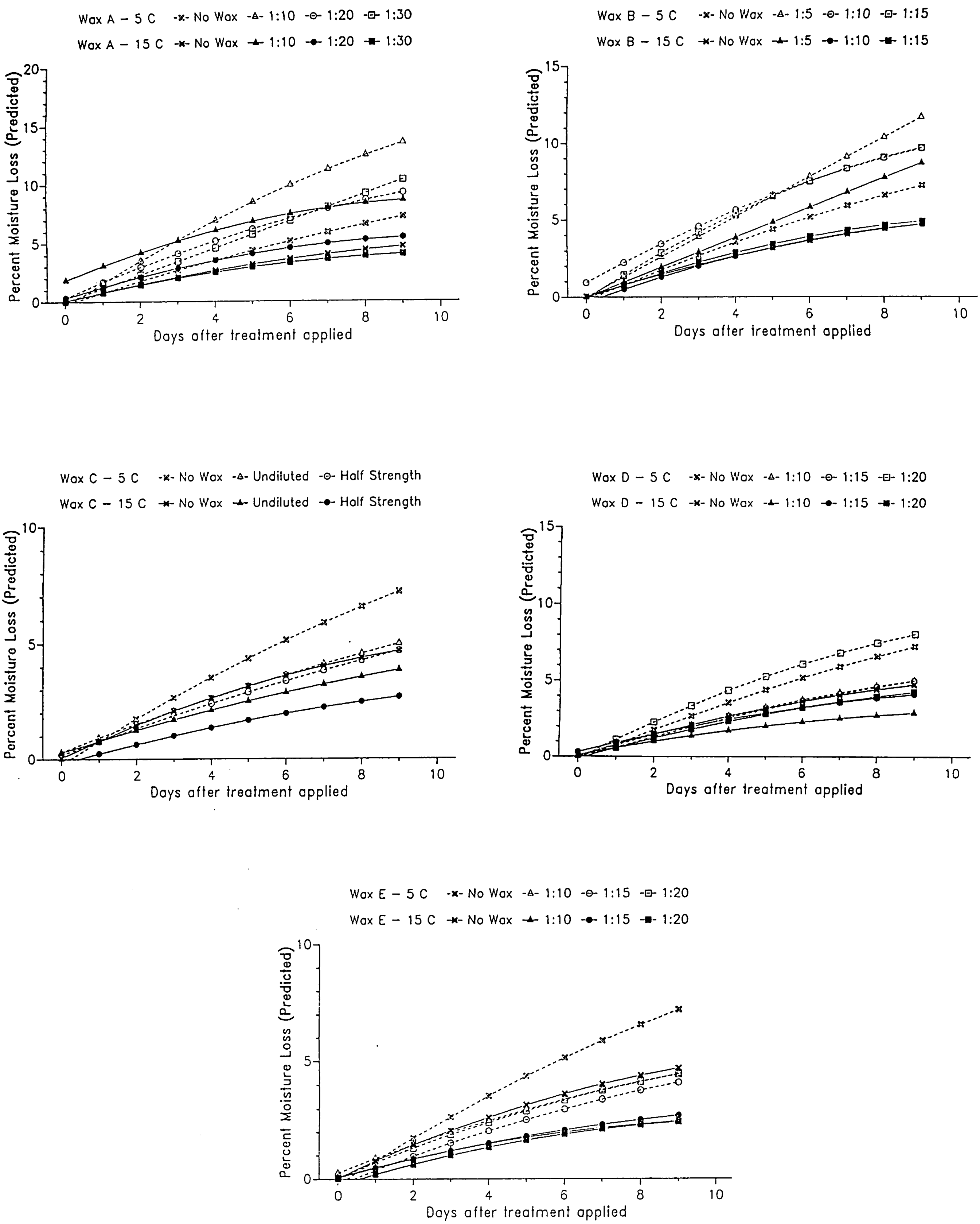

Figure 1. Predicted moisture loss based on average daily weight loss of unwaxed and waxed cucumber fruit stored for seven days at 5°C followed by two days at 15°C. Dilutions of the waxes are given in the text.

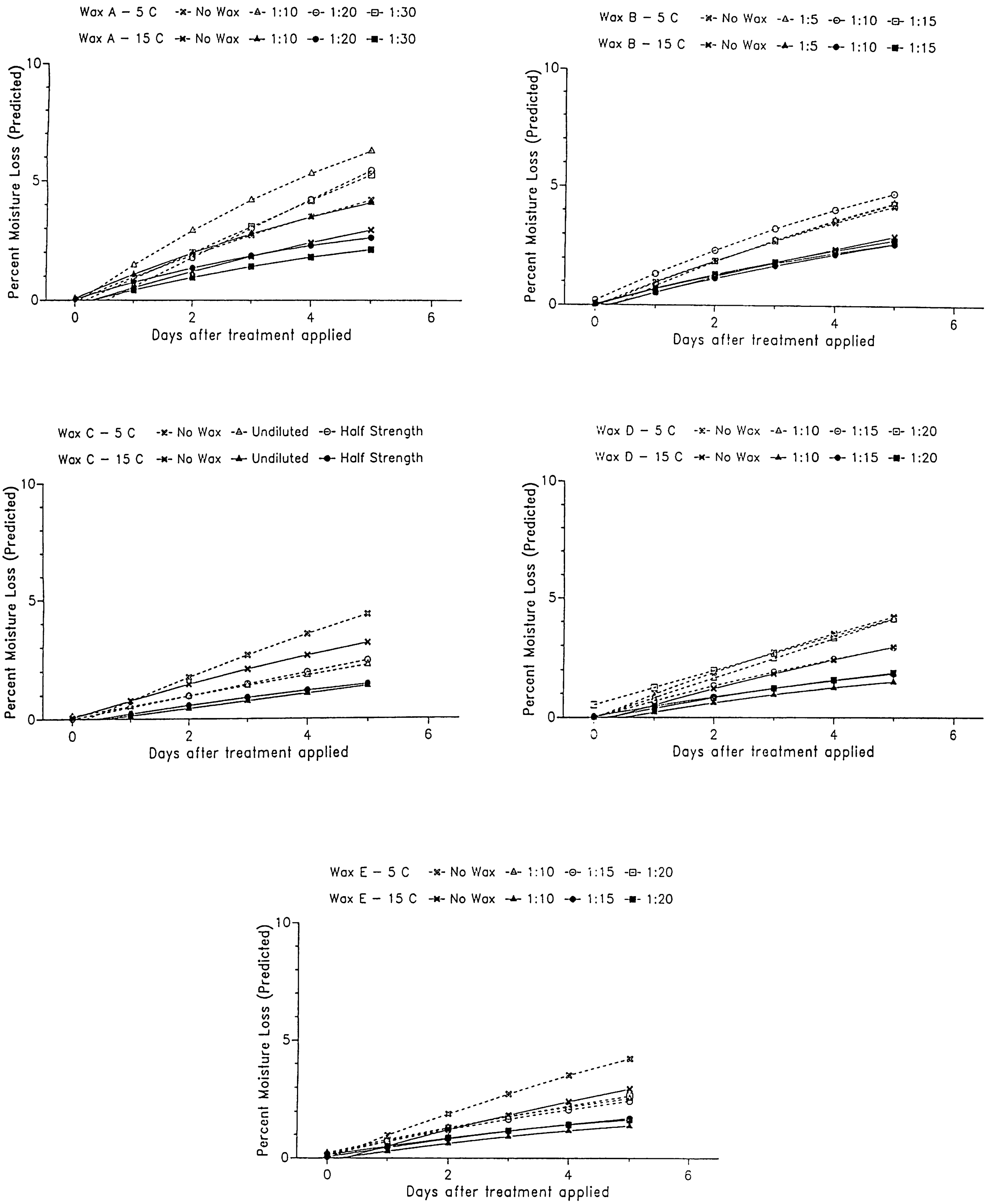

Figure 2. Predicted moisture loss based on average daily weight loss of unwaxed and waxed cucumber fruit stored for five days at 5°C. Dilutions of the waxes are given in the text.

rates as the unwaxed fruit. All of the other waxes at all dilutions, except for the most dilute concentration of the natural products wax at 5°C, were effective in reducing moisture loss at both storage temperatures. Thus, there is an interaction between the waxes and storage temperature in altering moisture loss. The most effective waxes in retarding moisture loss were the carnauba-based wax (C) and the polyethylene emulsion (E).

The waxes also affected the development of CI in fruit stored at 5°C (Table 1). In Expt. 1, fruit waxed with waxes A and B developed CI symptoms to the same extent as the unwaxed fruit. Waxes C, D, and E, however, were effective in reducing CI symptom development. No CI symptoms developed in fruit stored at 15°C.

Since all fruit stored for seven days at 5°C developed moderate to severe CI symptoms, a second experiment was conducted where the fruit were exposed to 5°C for only five days followed by two days at 15°C (Table 1). Five days exposure of fruit to 5°C caused only slight CI in unwaxed fruit and fruit waxed with waxes C (the carnauba-based wax) and D (the natural products wax). Wax E, the polyethylene emulsion, reduced the severity of CI, compared to unwaxed fruit, and waxes A and B (the surfactant-based waxes) increased CI. Wax A caused more injury than wax B.

Moisture losses in Expt. 2 (Fig. 2) followed the same patterns that were observed in Expt. 1. Moisture losses with all dilutions of wax A were greater than with no wax at 5°C. However, only with the least dilute concentration of wax B was the moisture loss greater than the unwaxed fruit at 15°C. The carnauba-based wax (C) and the polyethylene emulsion (E) were again the most effective waxes in retarding moisture loss during storage at 5°C and 15°C.

The loss of moisture as water vapor from fresh fruits and vegetables to the atmosphere is governed by Fick's first law which states that the diffusion of gases through a barrier varies inversely with the permeability of the pathway and directly with the magnitude of the driving force (Nobel, 1974). The driving force for water vapor diffusion is the VPD of the atmosphere. In the present study the VPD's at the two storage atmospheres were similar (3.0 Pa at 5°C and 2.3 Pa at 15°C). Thus, the greater factor responsible for the differences observed in moisture loss was the permeability of the pathway.

Most fruits and vegetables are covered with a natural waxy cuticle and epicuticular waxes that resist the passage of water vapor through them. The structure of the epicuticular waxes appears to be more important than their thickness in retarding moisture loss from underlying tissues (Wills et al., 1981). Overlapping platelets of wax are more resistant to the penetration of water vapor than thicker, structureless wax. With overlapping platelets, the water vapor has to follow a more diverse path to reach the atmosphere. McDonald et al. (1993) found that interior canopy grapefruit had significantly less chilling injury and smaller wax platelets than exterior canopy fruit. Chemical composition of the wax also affects its ability to restrict moisture loss from the underlying tissues. Hagenmaier and Shaw (1991, 1992) found that the permeability of waxes containing polar ingredients to water vapor is sensitive to the relative humidity.

Cuticular transpiration, however, generally represents only a small part of the water loss from plant tissues. Most of the moisture lost from plant tissues is generally lost through pores, i.e. stomates and lenticels. Cracks in the epicuticular waxes also provide channels through which water vapor can escape into the atmosphere relatively uninhibited. Low temperature-induced cracking of the waxes might have caused some of the interaction observed between temperature and the various waxes. The interaction of wax components with the naturally occurring waxes on the surface of the cucumber fruit was not determined.

The role of moisture loss in exacerbating CI still is not known. McDonald et al. (1993) concluded that moisture loss may be less important to the development of CI in grapefruit than was previously thought. They suggested that the permeability of peel tissue to gases other than water vapor may also influence the expression of CI. Physical damage to the cuticular surface resulted in more severe pitting of bell pepper fruit at 1.7°C, perhaps due to water loss from the surrounding cells (Thompson, 1978), although free radical production has been implicated in membrane deterioration of wounded plant tissue (Thompson et al., 1987). Oxygen free radicals have been implicated as the mediator of membrane degradation in injuries associated with low temperature, desiccation and other environmental stresses (Scandalios, 1993). Thus, the enhanced permeability to oxygen could lead to increased generation of active oxygen species which overwhelms the antioxidant defense systems and results in injury of low temperature stressed plant tissues.

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