Blossom-end rot (BER) of fruit is a physiological disorder that causes extensive losses of tomato production in fields or greenhouses. Blossom-end rot has long been recognized as Ca-deficiency disorder (Evans and Troxler, 1953; Geraldson, 1957; Maynard et al., 1957), which may be induced by drought (Stout, 1934), salinity (Robbins, 1937), K fertilization (Raleigh and Chucka, 1944), NH$_4^+$ fertilization (Spencer and Beckenbach, 1949), and low Ca supply (Lyon et al., 1942). The form of N fertilization in relation to BER has been investigated considerably because of the strong restrictive effects that NH$_4^+$ has on cation accumulation by plants (Barker et al., 1966; Pill et al., 1978; Wilcox et al., 1973).

In agreement with other researchers (Pill and Lambeth, 1980; Pill et al., 1978; Wilcox et al., 1973), we have noted a high incidence of BER on tomatoes grown with NH$_4$-N and have observed also that BER-affected fruit ripen more rapidly than normal fruit (unpublished data). A significant correlation between incidence of BER and uniform ripening was noted among some tomato genotypes (Trinklein and Lambeth, 1976). The phenomenon of early ripening of BER-affected fruit may be controlled endogenously by Ca levels (Rigney and Wills, 1981; Wills et al., 1977) and ethylene production in the fruit (Hoffman and Yang, 1980). Ammonium nutrition suppresses Ca accumulation by plants (Greenleaf and Adams, 1969; Pill et al., 1978), perhaps resulting in restricted Ca levels in fruit and advanced ripening (Rigney and Wills, 1981; Wills et al., 1977). Ethylene evolution by tomato foliage is enhanced markedly by NH$_4^+$ toxicity (Corey et al., 1987). Perhaps the stress of NH$_4^+$ toxicity also enhances ethylene biosynthesis by fruit. The present research investigated the relationships among NH$_4$-N nutrition, Ca accumulation, and ethylene production by fruit that were damaged by BER.

Materials and Methods

This research was conducted in the spring and summer seasons in the greenhouse and field in 1990. In one experiment started in April in the greenhouse, ‘Heinz 1350’ tomato plants were grown in a soil-based medium [7 sandy loam : 2 peatmoss : 2 sand (by volume) with 3 g limestone and 3 g ordinary superphosphate, 0N–8.8P–0K (per liter)] in 8.5-liter plastic nursery pots (21.5 × 21.5 cm). Ten plants in each of two nutritional regimes were grown in a completely random design. One regime provided N nutrition from daily applications of 100 ml 0.02 M (NH$_4$)$_2$SO$_4$ to impose NH$_4^+$ toxicity, as indicated by the development of BER and stem lesions (Maynard et al., 1966). Plants in the other regime were fertilized biweekly with 400 ml 20N–8.8P–16.6K fertilizer (urea, ammonium phosphate, and potassium nitrate) supplying 200 mg N/liter; 26% of the initial supply of N from this fertilizer was as NO$_3^-$. Because of the inclusion of NO$_3^-$ in the fertilizer and likelihood of nitrification in the medium, the plants were identified as NO$_3$-grown plants. The latter regime produced plants with no toxicity or deficiency symptoms and no BER. The fruit harvested from this experiment were used to compare ethylene evolution and NH$_4$-N accumulation by normal and BER-affected fruit from NH$_4$-stressed plants and normal fruit from unstressed (NO$_3$-grown) plants. Green fruit were used in these comparisons. Preclimatic fruit such as these generally have low ethylene evolution rates (Hoffman and Yang, 1980).

In another experiment started in March, ‘Vendor’ tomato plants were grown in a peatmoss–vermiculite–perlite medium (peat-lite) and fertilized with the same urea, ammonium phosphate, and potassium nitrate fertilizer. None of the 10 plants in this group showed any foliar toxicity or deficiency symptoms, but BER frequency was high among the fruit. After ethylene evolution was measured in fruit from this group of plants, half of the plants was fertilized with Ca(NO$_3$)$_2$ to provide 1 g Ca/pot (8.5-liter containers). Two weeks after fertilization, fruit were taken to determine Ca concentration.

In the field experiment started in May in a Hadley fine sandy loam at South Deerfield, Mass., ‘Heinz 1350’ plants were fertilized only with 80 kg N/ha from NH$_4$NO$_3$ applied before planting. None of these plants showed foliar toxicity or deficiency symptoms, and none produced fruit with BER. Fruit from this experiment were used to determine ethylene evolution and NH$_4$-N accumulation at different stages of ripening: green, 100% green; breaker, <10% pink or red; turning, 10% to 30% tannish yellow, pink, or red; ripe, >60% pink or red. These groupings were used because there were no differences in ethylene evolution between immature green or mature green fruit or among fruit ripened past the turning stage.

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In all experiments, ethylene was measured with whole fruit sealed in wide-mouth canning jars fitted with rubber septa in screw-top lids. Portions of the atmosphere in the jars were removed with a syringe to analyze ethylene evolution by gas chromatography (Corey et al., 1987). After ethylene evolution was determined, fruit were sectioned radially, and 10-g portions were saved for NH$_4$-N analysis. The remaining portions of the fruit were weighed and dried to determine dry weights for calculating NH$_3$-N on a dry-weight basis and for elemental analyses. Ammonium-N was determined volumetrically (Barker and Volk, 1964) on extracts made by homogenizing the 10 g of fruit in 50 ml of 1 M KCl + 0.02 M CuSO$_4$ and vacuum-filtering the homogenate. Fruit pH was determined electrometrically with a glass electrode and saturated calomel standard electrode on fruit juice extracted by mashing the fruit with a mortar and pestle and vacuum-filtering the resulting pulp. Calcium, Mg, and K concentrations were determined by atomic absorption spectrophotometry on 1 M HCl extracts of the dried fruit samples (Sahrawat, 1987). All determinations were made on at least duplicate samples of fruit taken on a given day, and replications were provided by repeating these determinations with new fruit on different days. Data were processed by analysis of variance (Steele and Torrie, 1980).

Results

Ethylene evolution and ammonium accumulation by fruit. Ethylene evolution and NH$_4$-N accumulation are reported for green fruit with or without BER from plants receiving NH$_4$-N nutrition and by unblemished fruit of ‘Heinz 1350’ plants receiving NO$_3$-N nutrition (Fig. 1). Fruit with BER had the highest rates of ethylene evolution of the group. Fruit without BER from plants receiving NH$_4$-N nutrition had much lower ethylene evolution but did not have NH$_4$-N concentrations different from those of the fruit showing BER. On one occasion, NH$_4$-grown fruit without BER at harvest developed BER after 24 h of storage at room temperature. None of the fruit from plants receiving NO$_3$-N nutrition had BER, and all had low ethylene evolution rates and NH$_4$-N accumulation relative to the fruit from plants receiving NH$_4$-N nutrition.

‘Vendor’ tomatoes grown in peat-lite had high incidences of BER at the green, breaker, turning, and ripe development stages. Ethylene evolution by these fruit rose with increasing ripening stage, but there were no differences in ethylene evolution between fruit with and without BER (Fig. 2). Ammonium-N accumulation did not vary with BER condition of fruit, averaging 0.14 mg N/g fresh weight in fruit with BER and 0.18 mg N/g fresh weight in fruit without BER. These concentrations of NH$_3$-N are about half of those occurring in fruit of plants grown with NH$_4$-N (Fig. 1).

Ethylene evolution by ‘Heinz 1350’ tomatoes grown in the field with NO$_3$-N increased with advancing ripening stage (Fig. 3). Ammonium-N concentrations did not vary with ripening stage, remaining at ≈0.15 mg N/g fresh weight, essentially the same as those in ‘Vendor’ tomatoes.

Calcium in fruit. Calcium concentrations were higher in ‘Heinz 1350’ fruit receiving NO$_3$-N nutrition than in fruit of plants receiving NH$_4$-N nutrition (Table 1). Calcium did not differ with respect to BER incidence on the NH$_4$-grown fruit. Concentrations of Mg or K did not vary with fruit condition or nutritional status (Table 1). With ‘Vendor’, Ca concentrations differed slightly but significantly whether the fruit had BER or not (Table 2). Fertilization with Ca increased fruit Ca, with measurements taken 2.5 weeks after Ca fertilizer was applied. Blossom-end rot at this time was confined largely to ripe fruit, with very few green fruit having BER, a result indicating that fertilization had arrested BER development. Ripe fruit had higher Ca than green fruit, with the increases in fruit Ca being restricted to fruit from fertilized plants. Neither K nor Mg varied with BER status, with an average K concentration of 2.57% and an average Mg concentration of 0.16% on a dry-weight basis.

Fruit pH. The juice extracted from green ‘Heinz 1350’ fruit with NH$_4$-induced BER was pH 5.5, which was higher than that (pH 4.5) from fruit of NO$_3$-grown plants. Extracts from NH$_4$-grown fruit without BER were pH 5.4. For ripening fruit with NH$_4$-induced BER, juice pH was 4.8. Juice from ripening NO$_3$-grown fruit was pH 4.4.
Discussion

Plants stressed by NH$_4$-N nutrition produced fruit with high incidences of BER. These fruit accumulated higher NH$_4$-N concentrations, had higher ethylene evolution rates when green, and had lower Ca concentrations than unblemished fruit from plants receiving NO$_3$-N nutrition. The accumulation of NH$_4$-N was a unique characteristic of fruit from plants grown on NH$_4$-N, for neither normally ripening fruit nor BER fruit of plants receiving NO$_3$-N showed enhanced NH$_4$-N levels. Stresses such as NH$_4^+$ toxicity (Corey et al., 1987), certain nutrient deficiencies (Feng

Table 1. Elemental composition of 'Heinz 1350' tomatoes with or without blossom-end rot (BER) from plants grown on NH$_4$-N or NO$_3$-N nutrition.

| Condition of fruit Concn (mg·kg$^{-1}$ dry wt) |
|-----------------|---------|---------|---------|
| N source BER$^a$ | Ca      | Mg      | K       |
| NH$_4$ BER      | 390 a   | 1141 a  | 26,062 a|
| NH$_4$ No BER   | 382 a   | 1106 a  | 25,280 a|
| NO$_3$ No BER   | 682 b   | 1209 a  | 25,502 a|

$^a$Condition at harvest. None of the NO$_3$-N-grown tomatoes had BER. Mean separation within columns by LSD at $P \leq 0.01$. 

Fig. 2. Ethylene evolution of 'Vendor' tomatoes at different ripeness stages with or without blossom-end rot (BER). Results of analysis of variance: BER, nonsignificant; ripeness, significant ($P \leq 0.01$); BER × ripeness, nonsignificant.

Fig. 3. Ethylene evolution and NH$_4$-N concentrations in 'Heinz 1350' tomatoes at different ripeness stages. Results of analysis of variance: ethylene, significant increase with ripening ($P \leq 0.01$); NH$_4$-N, no change with ripening.
and Barker, 1992a), and salinity (Feng and Barker, 1992b) lead to NH$_4$-N accumulation in tomato foliage. Ammonium-N accumulation seems to be followed by ethylene evolution (Barker and Corey, 1991; Feng and Barker, 1993). With plants grown with NH$_4$-N, we noted that NH$_4$-N accumulated in fruit without BER and that ethylene evolution was lower from these fruit than from those with BER. These observations and BER development during storage of harvested, green, NH$_4$-grown fruit suggest that NH$_4$-N accumulation precedes BER development and ethylene biosynthesis. Perhaps, in parallel with the physiology of foliage, NH$_4$-N accumulation in green fruit initiates injury and processes that lead to ethylene evolution (Barker and Corey, 1991).

The finding of lower total Ca concentrations in NH$_4$-grown fruit agrees with results in which NH$_4$-N nutrition or depressed Ca levels were related to enhanced BER incidence (Greenleaf and Adams, 1969; Pill et al., 1978). Fruit with BER from plants grown with NH$_4$-N had about half the Ca concentration of unblemished fruit from plants grown with NO$_3$-N. With plants on NO$_3$-N nutrition, differences in fruit Ca concentrations were small but significant between BER and normal fruit. Although it is understood clearly (Geraldson, 1957; Maynard et al., 1957) that BER is a result of Ca deficiency, attempts to demonstrate that fact through fruit analyses have not always been successful (Murray et al., 1972; Pill and Lambeth, 1980). Differences in Ca distribution (Pill and Lambeth, 1980) or relationships of Ca with K and Mg in fruit (Murray et al., 1972) have been offered as explanations for the lack of correlation between BER and total fruit Ca. We did not measure Ca partitioning in fruit, but observed no special relationships among Ca, K, and Mg in fruit with BER, regardless of source of N nutrition.

Some similarities between the physiological responses of NH$_4$-stressed fruit and bruised or diseased fruit are apparent. Bruised mature-green fruit ripened quickly and had higher ethylene evolution rates and lower titratable acidity than unblemished fruit (MacLeod et al., 1976). Ripe fruit infected with alternaria (Alternaria tenuis) or anthracnose (Colletotrichum coccodes) had higher pH and lower titratable acidity than uninfected fruit (Sapers et al., 1978). Ammonium accumulation was not measured in the previous studies; however, NH$_4$ has been shown to accumulate in disease-infected leaves and to be a causal agent in the injury resulting from the infections (Bashan et al., 1980; Lovrekovich et al., 1970). The deleterious effects of bruising and disease infection may have been due to NH$_4$ accumulation induced by these injuries.

The increased ethylene evolution rates and apparently increased ripening rates by green fruit from plants grown with NH$_4$-N seem to be the result of stresses imparted by NH$_4$-N accumulation in the fruit. Our results show that NH$_4$-N accumulation was confined to NH$_4$-grown plants, was not associated with normal fruit ripening, and did not occur in fruit with BER induced by factors other than NH$_4$-N nutrition. The results also suggest that restricted Ca accumulation by fruit of plants grown with NH$_4$-N was associated with BER development.

**Table 2. Concentrations of Ca in ripe or green ‘Vendor’ tomatoes with or without blossom-end rot (BER) and before or after Ca fertilization.**

| Condition of fruit | Before fertilization | After fertilization | Ca concn (mg·kg$^{-1}$ dry wt) |
|--------------------|----------------------|---------------------|--------------------------------|
|                    | Green                | Ripe                | Mean (ripeness × fertilization) | Mean |
| BER                | 625                  | 563                 | 660 a $^a$                      | 669  |
| No BER             | 694                  | 669                 | 1118 b                          | 1377$^b$ |
| Mean (ripeness × fertilization) | 660 a $^a$          |                      | 1118 b                          | 1377$^b$ |

$^a$Mean separation within the ripeness × fertilization interaction was nonsignificant.

$^b$Significant by F test at P ≤ 0.05 or 0.01, respectively.

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