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Blossom-end Rot of Tomato Fruit as Influenced by Osmotic Potential and Phosphorous Concentrations of Nutrient Solution Media[1]

Antonio Cerda[2], F. T. Bingham, and C. K. Labanauskas
Departments of Soil and Environmental Sciences and Botany and Plant Sciences, University of California, Riverside, CA 92521

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Abstract. **Tomato plants (*Lycopersicon esculentum* Mill.) were grown to maturity in complete nutrient solution with osmotic potentials ($^s\psi_o$) of −0.8, −2.4, −4.4 and −6.4 bars from NaCl additions, and 0.5, 5.0, and 50 ppm P as variables. The objectives were to evaluate the effects of $^s\psi_o$ and P and their interactions with respect to fruit yield and quality, and nutrient concentrations in the plants and fruits. Reducing the $^s\psi_o$ (increasing negative values) by NaCl addition significantly decreased tomato fruit yield, but increased the percentages of soluble solids, total solids, blossom-end rot (BER) incidence and non-marketable fruit. Increased solution salinity resulted in higher leaf concentrations of P, Na and Cl. Increased nutrient solution P levels (P_s) significantly increased fruit yield, but decreased the percentage of fruit soluble solids and BER incidence. Leaf P, Ca and Cl concentrations of plants grown in the high P nutrient solution were higher than those of the leaves from low P solution plants. The incidence of BER was greatest under low $^s\psi_o$ and low P_s. Reduced Ca concentrations of leaves and mature fruit were associated with the BER development. The Ca concentration of mature normal fruit varied from 0.039 to 0.076% compared with 0.028 to 0.043% for mature BER fruit. Leaf Ca concentrations of 1.5 to 2.0% were associated with the BER condition.**

Blossom-end rot (BER) is a widespread physiological disorder that affects tomato, pepper (*Capsicum frutescens* L.) and other species. This disorder is reported in virtually every tomato- and pepper-producing areas of the world and causes serious losses of marketable fruit. Generally, this disorder is attributed to an imbalance of Ca and/or water stress. Details of BER of tomato fruit with reference to Ca are discussed by Spurr (14), Barke and Menary (2), Pill et al. (11), Van Goor (15, 16), Evans and Troxler (5), Geraldson (7), Wiersum (20) and others (10, 17, 18, 19).

Ward (17, 18) had suggested a leaf Ca value of 1.5% as optimal for production of BER-free tomato fruit and less than 1.0% Ca as suggestive, and a normal fruit Ca level to be about 0.08%, whereas that of BER – from 0.02 to 0.07%. Evans and Troxler (5) found Ca concentrations in tomato fruit with and without BER to be 0.10-0.13% and 0.17%, respectively. Maynard et al. (10) found 0.04 and 0.07% Ca for BER and normal fruit, respectively. Van Goor (15) reported 0.03 to 0.04% Ca for BER and 0.09% Ca for normal fruit. Wiersum (20) gave concentrations of 0.08 and 0.18% Ca for BER and normal fruit, respectively. Spurr (14) did not find a difference between Ca content of BER and normal mature fruit. Barke and Menary (2) found that when the total nutrient concentrations varied but the proportion of Ca was constant, BER incidence was inversely related to fruit Ca levels over the whole range of treatments used. Thus, in their experiment, the BER incidence could be related to leaf Ca content or even total Ca absorbed by the plants at high soil nutrient concentrations. The data presented in the published research papers show that there are discrepancies in reported values for Ca in fruit with and without BER.

Robbins (13) related BER incidence in tomato fruit to water stress brought about by salinizing the substrate to induce plant osmotic stress. Likewise, Hayward and Long (8) related BER development to salinity stress. Raleigh and Chucka (12) further investigated the effects of varying substrate osmotic potentials in combination with nutrient levels and found that Ca nutrition was critical to BER development. Van Goor (16) reported that BER incidence of tomatoes can be correlated with a low Ca content in the fruit; that the nutritional disorder can be aggravated by water stress; and that under influence of osmotic stress the relative Ca-content is lowered. Westerhout (19) suggested that the movement of Ca to fruit was restricted in tomato plants suffering from moisture stress. Martin and Lewis (9) found that Ca can be actually withdrawn from apple fruits under period of water stress. Wiersum (20) demonstrated that during periods of rapid fruit growth or reduced fruit transpiration, the supply of Ca to tomato fruits may be limiting.

Pill et al. (11) found that NH_4-N nutrition, in comparison to NO_3-N nutrition of tomato plants grown in sand culture reduced leaf and fruit Ca, and that the incidence of BER was increased. Arnon and Hoagland (1) observed and increased tomato BER incidence in P-deficient solution cultures. Foster (6) found a greater incidence of tomato BER when superphosphate was omitted. Information pertaining to the role of P nutrition as it affects BER development is limited.

The evidence to date implies that the BER in tomatoes is a quantitative phenomenon. This means that quantitative plant parameters are associative and not causal. The data presented in the literature clearly imply that a number of parameters such as Ca assimilation and translocation, substrate P level (P_s), substrate osmotic potential ($^s\psi_o$), and plant water relations affect BER. To further elucidate the mechanisms of BER development, the present experiment was designed to determine the effect of $^s\psi_o$ and P_s on tomato growth, yield, fruit quality, nutrient concentrations in leaves, fruit, juice of tomato, and to assess the degree of BER incidence in tomato fruit.

Materials and Methods

Seeds of 'VF-145-B-7879' tomato were germinated in sand. After 20 days, (September 22, 1976), 2 uniform seedlings each were transplanted to plastic tanks containing 110 l of an aerated nutrient solution of the composition: $Ca(NO_3)_2$, 9 meq/liter; KNO_3, 3 meq/liter; K_2SO_4, 3 meq/liter; $MgSO_4$, 4 meq/liter; 5 μg/liter of Fe added as Fe-EDTA; and 0.5, 0.05, 0.5, 0.01, 0.05 ppm of B, Cu, Mn, Mo, and Zn, respectively. Three P_s levels (0.5, 5.0, and 50.0 ppm) were combined factorially

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[2]Present address: Centro de Edafologia y Biologia Aplicada del Segura (CEBAS), Murcia, Spain.

with 4 $^s\psi_o$ levels (–0.8, –2.4, –4.4, and –6.5 bars) giving 12 different treatments which were replicated 3 times in a randomized block design.

Culture solutions were salinized with NaCl to the desired $^s\psi_o$ levels 15 days after transplanting the seedlings to the nutrient solution. Twenty four meq NaCl/liter of nutrient solution lowered the $^s\psi_o$ of the nutrient solution by one bar. The addition of NaCl was done stepwise by lowering the $^s\psi_o$ of the solution by 1 bar per day. Culture solution volume was maintained by adding deionized water daily. The pH was maintained between 5.5 and 6.5 throughout the experiment by the addition of HNO_3 or KOH. P concentrations were checked weekly and adjusted to the original concentration. The other major elements (N, K. Mg and S) were adjusted twice during the experiment. The solution Ca concentration was never less than 7 meq/liter. The greenhouse temperature was maintained at 22 to 28°C.

At the early fruit formation stage when the fruit was 2.5 cm (1 inch) in diameter, the most recently fully developed mature leaves were sampled for chemical analysis. The leaf samples were washed, dried, ground and analyzed by the same procedures as previously described (3). The experiment was completed on January 9, 1977. The BER incidence was noted and calculated as a percentage of the total fruit number harvested.

Eight normal mature fruits from each replicate were chemically analyzed. This number, however, was variable in certain treatments owing to BER presence. Immediately after fruit was harvested, the epicarp and seeds were removed. The fruit samples then were dried at 70°C for 3 days and ground in a Wiley mill. One g samples of ground fruit were digested with 4 ml HNO_3-$HClO_4$ acid, 2:1, by volume, until the mixture became colorless; deionized water was added to the final 25 ml volume. These solutions were analyzed for Ca, Mg, Zn, Mn and Fe by atomic absorption using a Perkin-Elmer Model 103 Atomic Absorption Spectrophotometer. K and Na were analyzed by flame photometry. P was determined colorimeterically using the molybdenum-blue method (4). Separate ground fruit portions were analyzed for Cl and total N by the methods described by Chapman and Pratt (3), with modification of the micro-Kjeldahl method to include NO_3-N.

After removal of epicarp and seeds, the fruit was homogenized for the determination of fruit quality. Total percentage solids were determined gravimetrically by drying 10 g of homogenate at 70°C for 48 hr. Separate samples of homogenate were filtered for measuring soluble solids, pH, electrical conductivity (EC), and titratable acidity. Soluble solids were determined by drying 10 g of the filtered portion at 70°C for 48 hr. Insoluble solids were calculated as the difference between total and soluble solids. The EC was measured at 25°C with a conductivity bridge. Titratable acidity was determined by titration with 0.1N NaOH using phenolphthalein as the indicator. The pH determinations were made with a pH meter.

Results

Osmotic potential effects ($^s\psi_o$). Reduction of $^s\psi_o$ by NaCl addition to the nutrient solution resulted in significant decreases in fresh weight of shoots, roots, fruit number, and fruit weight as compared with plants grown in the unsalinized nutrient solution (Table 1). Percentages of fruit soluble and total solids, fruit EC, BER incidence and non-marketable fruit generally increased as $^s\psi_o$ decreased (Table 1).

Leaves from plants grown in the lowest $^s\psi_o$ solutions contained higher P, Na and Cl, and lower NO_3-N and Mg concentrations than those of plants grown in low salt nutrient solutions (Table 2). Other nutrients in the leaves were not affected significantly by $^s\psi_o$ treatments. Reduction of $^s\psi_o$ produced a significant increase in fruit Na, Cl and Zn, and decrease in fruit Mg. Fruit juice K, Na and Cl concentrations from plants grown in the low $^s\psi_o$ nutrient solution were substantially higher than those from plants grown at higher osmotic potentials. Fruit Ca, Mn, K, P and total N concentrations were unaffected by $^s\psi_o$ (Table 2).

Phosphorus effects (P_s). Increasing P_s increased the shoot and root fresh weights, fruit yield and number per plant, and only slightly increased the fruit weight (Table 1). The percentages of fruit soluble solids and BER were generally decreased by increasing P_s (Table 1). Increased P_s increased leaf P, Ca and Cl, and fruit P concentrations (Table 2). Intermediate P_s increased the fruit and juice Na concentration compared to the highest P_s (Table 2). Fruit Cl concentration was increased by the intermediate P_s compared to the lowest P_s (Table 2).

There was only one significant interaction between $^s\psi_o$ and P_s on fruit P (Table 3). Increasing P_s levels of nutrient solutions at $^s\psi_o$ of –0.8 and –2.4 bars led to increased P concentration in the fruit; on the other hand, increased levels of P in the –4.4 and –6.4 bars nutrient solutions did not lead to a substantial increase in the P concentration in fruit of tomato plants.

Discussion

Substrate osmotic potential ($^s\psi_o$) and P_s influenced yield, nutrient concentrations, and particularly BER which in turn affected the quality of the marketable fruit produced. Reduction in $^s\psi_o$ of the nutrient solution led to a greater incidence of BER, whereas increased P_s levels resulted in increased yield of fruit and in a significantly lower incidence of BER (Table 4).

Although leaf Na and Cl concentrations were increased due to addition of NaCl to the solution culture (Table 2), the resultant leaf concentrations (Na, 0.16 to 0.74%; Cl, 1.16 to 5.13%) were evidently not high enough to cause leaf toxicity symptoms such as necrosis. The leaf NO_3-N decreased from a maximum of 1.44% to a minimum 0.62% with NaCl additions. The incidence of BER while increased through additions of NaCl to the nutrient solutions is not uniquely associated with concentrations of Ca, P, Cl, or NO_3-N in leaf tissue.

The $^s\psi_o$ treatment led to reduced accumulation of Mg in the fruit, but not Ca, and increased accumulations of Na, Cl and Zn. Mature tomato fruit without BER varied from 0.04 to 0.08% Ca; the lower concentration being in fruit from the salinized (S_4) and lower P treatments (P_1 and P_2). These treatments produced the greatest incidence of BER (Table 4). The Ca concentration in fruit with and without BER was on an average basis 0.04% and 0.08%, respectively. The lower Ca values were, in general, characteristic of fruit with BER. These findings are in agreement with those reported by Van Goor (15, 16), Ward (18), Wiersum (20), and Maynard et al. (10). According to Van Goor's (16) findings, water stress can be effective in two distinct manners. One is withdrawal of water from cells which are already susceptible to water extraction by their rather low Ca content. Thus, the water loss is then the cause of cell death. Another mechanism which, also has been suggested by Van Goor (16), is an indirect effect of water stress on mineral uptake on distribution, resulting in a lower Ca content in the apex of tomato fruit.

Blossom-end rot was most extensive in plants supplied with low P and high NaCl (P_s = 0.5 ppm × $^s\psi_o$ = –6.4 bars) (Table 4). This combination of treatments resulted in less Ca uptake and accumulation in leaf and fruit tissue. These findings support the observations made by Westerhout (19), who suggested that the movement of Ca to fruit was restricted in tomato plants suffering moisture stress. Wiersum (20) suggested that during periods of rapid fruit growth or reduced fruit transpiration, the supply of Ca to tomato fruits may be limited. Due to reduced fruit transpiration, movement of Ca to fruits via the xylem is reduced and such conditions would induce Ca deficiency in fruit. There are also some indications

Table 1. Yield, quality, and blossom-end rot (BER) incidence in tomatoes as affected by substrate salinity ($^s\psi_o$) and phosphorus (P).

Paremeters	$^s\psi_o$ levels in nutrient solution[z] (bars) S_1 −0.8	S_2 −2.4	S_3 −4.4	S_4 −6.4	P levels in nutrient solution (P_s)[y] (ppm) P_1 0.5	P_2 5.0	P_3 50	CV
Fresh wt shoot/plant (kg)	1.9B[x]	1.3C	0.8D	0.6D	0.8D	1.3C	1.4C	33
Fresh wt roots/plant (kg)	0.3C	0.2CD	0.2D	0.2D	0.2D	0.3C	0.2CD	36
Fruit yield/plant (kg)	5.7B	3.6C	1.6D	0.8D	1.9D	3.3CD	3.6C	43
Fruit number/plant	76.0C	55.0C	31.0D	22.0D	34.0D	50.0CD	53.0C	35
Fresh wt/fruit (g)	75.4A	64.0B	51.7C	38.1D	54.3d	56.3cd	61.3c	13
Titratable acidity (meq/liter)	59.4a	61.8a	61.9a	58.6a	64.1a	63.0a	54.1a	22
Soluble solids, juice (%)	4.1D	4.5CD	5.1BC	5.6B	5.2C	4.9CD	4.4D	11
Insoluble solids, juice (%)	0.9a	1.1a	1.0a	1.2a	0.9a	1.0a	1.3a	36
Total solids/fruit (%)	5.1D	5.6D	6.2BC	6.8B	6.2a	5.9a	5.6a	12
EC of fruit filtrate (mmhos/cm)	5.3D	6.3C	7.2B	8.4A	6.9cd	7.0c	6.4d	8
pH of fruit filtrate	4.2a	4.2a	4.2a	4.2a	4.2a	4.2a	4.2a	2
Blossom-end rot/plant (%)	7.8D	10.53D	11.8CD	23.8C	24.6C	10.1D	5.4D	68
Non-marketable fruit/plant (%)	13.8D	13.5D	17.6D	35.7C	24.6a	21.0a	14.8a	66

[z]Each value is a mean of 9 individual determinations.

[y]Each value is a mean of 12 individual determinations.

[x]Mean separation in rows by Duncan's multiple range test, 5% level (lower case letters), 1% level (upper case letters).

CV = Coefficient of variation as percentage.

Table 2. Mineral composition of tomato leaves, fruit, and juice as affected by substrate salinity ($^s\psi_o$) and phosphorus (P).[x]

Parameters	Oven-dried basis[x]	$^s\psi_o$ levels in nutrient solution[z] (bars) S_1 = −0.8 bars	S_2 = −2.4 bars	S_3 = −4.4 bars	S_4 = −6.4 bars	P levels in nutrient solution (P_s)[y] P_1 = 0.5 ppm	P_2 = 5.0 ppm	P_3 = 50 ppm	CV
NO_3-N leaves	(%)	1.44B[w]	1.00C	0.80CD	0.62D	1.07a	0.93a	0.88a	26
Total N, leaves	(%)	4.92a	4.75a	4.76a	4.94a	4.70a	5.00a	4.84a	8
Total N, fruit	(%)	2.66a	2.60a	2.76a	2.90a	2.57a	2.81a	2.81a	13
P, leaves	(%)	0.55CD	0.48D	0.66C	0.94B	0.94D	0.73C	0.75C	18
fruit	(%)	0.46a	0.46a	0.54a	0.54a	0.36D	0.57C	0.57C	19
K, leaves	(%)	3.84a	3.76a	3.81a	3.89a	3.98a	3.80a	3.70a	8
fruit	(%)	3.57a	2.89a	3.26a	3.11a	3.38a	2.94a	3.30a	21
juice	meq/liter	50.80D	55.21D	59.40D	71.70C	60.50a	61.60a	55.60a	14
Ca, leaves	(%)	2.50a	2.64a	2.63a	2.58a	1.84D	2.89C	3.03C	12
fruit	(%)	0.06a	0.06a	0.06a	0.04a	0.05a	0.06a	0.06a	10
Mg, leaves	(%)	0.71c	0.68cd	0.62cd	0.59d	0.68a	0.66a	0.62a	17
fruit	(%)	0.18C	0.17CD	0.16CD	0.15D	0.16a	0.17a	0.18a	14
Na, leaves	(%)	0.16D	0.32C	0.57B	0.74A	0.42a	0.46a	0.46a	14
fruit	(%)	0.11D	0.17D	0.27C	0.32C	0.23cd	0.24c	0.19d	21
juice	meq/liter	1.70D	3.60C	7.10B	9.20A	5.60cd	6.10c	4.50d	26
Cl, leaves	(%)	1.16D	2.39C	4.23B	5.13A	2.84D	3.35CD	3.49C	16
fruit	(%)	0.70D	1.04DC	1.46AC	1.67A	1.11D	1.34C	1.21DC	20
juice	meq/liter	9.60D	16.00D	25.20C	34.50B	21.10a	22.90a	20.00a	23
Zn, fruit	(ppm)	16.00D	16.00D	21.00C	21.00C	17.00a	19.00a	19.00a	14
MN, fruit	(ppm)	13.00a	13.00a	13.00a	11.00a	14.00a	12.00a	12.00a	23
Fe, fruit	(ppm)	54.00a	58.00a	50.00a	50.00a	60.00c	52.00cd	46.00d	23

[z]Each value is a mean of 9 individual determinations.

[y]Each value is a mean of 12 individual determinations.

[x]Mineral concentrations on dry wt basis.

[w]Means separation in rows by Duncan's multiple range test, 5% level (lower case letters), 1% level (upper case letters).

that Ca can be withdrawn from apple fruit under periods of water stress (9). Similar phenomenon may occur with tomato fruit. Blossom-end rot was least extensive in plants supplied with high P_s and low NaCl (P_s = 50 ppm × $^s\psi_o$ = −0.8 and −2.4 bars (Table 4). This combination of treatments resulted in higher Ca uptake and accumulation in leaf and fruit tissue. Thus, the findings presented in this paper support the previous findings that BER is due to a deficit of Ca in the fruit which is severely aggravated by water stress caused by high salinity.

Leaf Ca values of 2% or less sampled at the early fruiting stage when the fruit has 2.5 cm (1 inch) in diameter were indicative of pending development of BER fruit. The Ca content in BER fruit was found to be lower than in normal fruit (0.04% vs. 0.06% Ca). water stress may be a factor predisposing the tomato plant to a greater incidence of BER. Apart from difficulties in interpreting nutritional and water stress values, the

Table 3. Interaction effects of substrate salinity and phosphorus on fruit P concentration.

$s\psi_o$ (bars)	% P in dry fruit[z] P_s 0.5 ppm	5.0 ppm	50.0 ppm
−0.8	0.24d[y]	0.57ba	0.58ba
−2.4	0.27b	0.50ba	0.60ba
−4.4	0.42cd	0.65a	0.56ba
−6.4	0.52ba	0.58ba	0.53ba

[z]Each value is a mean of 3 individual determinations.

[y]Mean separation within columns and rows by Duncan's multiple range test, fruit P (5%).

Table 4. Blossom-end rot (BER) incidence as influenced by substrate salinity and phosphorus.[z]

$s\psi_o$ (bars)	BER incidence[y] (%) P_s 0.5 ppm	5.0 ppm	50.0 ppm
−0.8	22.0	1.0	1.0
−2.4	30.0	2.0	1.0
−4.4	21.0	8.0	6.0
−6.4	30.0	28.0	15.0

[z]Each value is a mean of 3 individual determinations; only main effects significant.

[y]BER incidence as a percentage of total fruit.

fact that BER is a quantative phenomenon. It implies that quantitative plant parameters are only associated but not causal. It is suggested by Pill et al. (11) that ontogenetic determinations of ion compositions of both leaves and fruits and plant water parameters, especially fruit transpiration, be made.

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