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Foliar application of calcium chloride and borax influences plant growth, yield, and quality of tomato (*Lycopersicon esculentum* Mill.) fruit

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Abstract: The influence of $CaCl_2$ and borax on growth, yield, and quality of tomato was investigated during the years 2009 and 2010. The experiment was laid out with a randomized complete block design. Calcium chloride (0.3% and 0.6%) and borax (0.2% and 0.4%) solutions were applied as foliar sprays either alone or in combination and data were recorded for plant height, branches per plant, flowers per cluster, fruits per plant, yield, fruit weight, fruit firmness, and total soluble solid content of the fruit. The application of $CaCl_2$ alone significantly increased the plant height and fruits per plant and decreased the incidence of blossom end rot. Borax alone significantly enhanced the number of branches per plant, number of flowers per cluster, fruits per cluster, fruits per plant, fruit weight, fruit firmness, and total soluble solid content of the fruits. Foliar application of $CaCl_2$ (0.6%) + borax (0.2%) resulted in the maximum plant height (86.60 cm), branches per plant (7.21), flowers per cluster (32.36), fruits per plant (96.37), fruit weight (96.33 g), yield (21.33 t ha^{-1}), fruit firmness (3.46 kg cm^{-2}), and total soluble solids (6.10%) and the lowest blossom end rot incidence (6.25%). However, the difference among 0.6% $CaCl_2$ + 0.2% borax, 0.3% $CaCl_2$ + 0.2% borax, and 0.6% $CaCl_2$ + 0.4% borax was nonsignificant.

Key words: Borax, calcium chloride, foliar application, fruit quality, tomato

Introduction

Tomato is one of the most popular and widely grown vegetable crops, ranking second in importance to potato in many countries (Hartmann et al. 1981). In Pakistan, 2 crops of tomato are produced annually: summer and winter crops. The winter crop is limited to frost-free areas (Shahid 1999). The yield of tomato in Pakistan is 10.1 t ha^{-1}, which is much lower than the international standard (Akhtar et al. 2010). The application of less-than-optimal fertilizers decreases the yield and quality of tomato fruit (Kiviani et al. 2004). The yield and fruit quality depends on the cultivar and the climate in which it is grown (Marsici et al. 2011), as well as an optimum supply of fertilizers (Ahmad et al. 2011). Generally, a balanced supply of nutrients is essential for optimum yield and fruit quality (Akhtar et al. 2010). Calcium is an important nutrient that plays a key role in the structure of cell walls and cell membranes, fruit growth, and development, as well as general fruit quality (Kadir 2004). It enhances resistance to bacterial and viral diseases (Usten et al. 2006). The calcium taken up

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from the soil is translocated to the leaves but very little goes from the leaves to the fruit (Kadir 2005). Therefore, plants need a constant supply of calcium for vigorous leaf and root development and canopy growth (Del-Amor and Marcelis 2003). Boron is also an important micronutrient that is easily leached from the soil and its deficiency can occur in tomatoes grown under heavy rainfall conditions (Passam et al. 2007). Boron deficiency appears as thickened, wilted, or curled leaves and the cracking and rotting of fruit, tubers, or roots. Adequate B levels help to maintain leaf K levels in tomato during fruit development (Sperry 1995). Foliar application of boron is preferred over soil application because of the very narrow range from deficient to toxic levels (Reisenauer et al. 1973). According to Tariq and Mote (2007), the benefits of Ca and B application depend on a balance between Ca and B levels in the plant. Generally, low Ca and high B could be detrimental to plant growth and yield (Tariq and Mote 2007). The current study was therefore initiated to investigate the influence of foliar application of calcium and boron either alone or in combination on the growth, yield, fruit quality characteristics (e.g., size, firmness, total soluble solid [TSS] content), and blossom end rot incidence of tomato fruit.

Materials and methods

The research study was conducted at the KPK Agricultural University, Peshawar, during 2009 and 2010 to determine the influence of foliar $CaCl_2$ and borax application on growth and yield performance of tomato. Data from the 2 years were averaged to represent each treatment.

Seeds of tomato cultivar Roma were sown in the month of January and were transplanted during the month of March. There were 3 ridges in 1 subplot and 10 plants in each ridge. Row-to-row distance and plant-to-plant distance was 75 cm and 30 cm, respectively.

The soil of the experimental field was silty loam in texture with a pH of 7.7. The experimental field was fertilized with recommended doses of NPK fertilizers at 100, 90, and 60 kg ha^{-1}, respectively (Siddiq et al. 2009). Phosphorous and potassium were applied before transplanting the seedling. Nitrogen fertilizer was applied in 2 split doses, the first before and the second 25 days after transplanting. Calcium chloride (0.3% and 0.6%) and borax (0.2% and 0.4%), either alone or in combination, were applied as foliar spray 30 days after transplanting and when the fruits were berry-sized. Calcium chloride and borax solutions were prepared from analytical grade chemicals. A back-held spray pump was used for foliar application of the chemicals. After each treatment, the pump was washed thoroughly. A teaspoon of commercial washing powder was added as a wetting agent. Tap water containing a comparable amount of wetting agent was sprayed on the plants in the controlled treatment. All foliar spraying was carried out early in the morning.

The experiment was laid out in randomized complete block design with 3 replications. The data were analyzed using MSTAT-C software and treatment means were separated by the least significant difference (LSD) at a 0.05% level of significance (Steel and Torrie 1984).

Plant height was determined for 5 plants in the middle row in each treatment after the first picking. For this purpose, the plant height from the soil line to the top was determined with a measuring tape and averaged to represent corresponding treatments. The number of branches was counted for the middle ridge in each treatment at the first picking and the average number of branches per plant was calculated.

The number of flower clusters per plant, number of fruits per cluster, and number of fruits per plant were determined for 5 plants in the middle row of the plot. For this purpose, the number of flower clusters per plant, number of fruits per cluster, and number of fruits per plant were counted and divided by the total number of plants. The total yield for each treatment was calculated by weighing the fruit picked in each plot and converting the weight to yield per hectare. The average fruit weight was estimated by weighing 10 fruits in each treatment, with the help of an electronic balance measuring in grams to the third decimal place, and then converting to average fruit weight.

Blossom end rot incidence (%) was estimated by counting the total number of fruits and fruits showing symptoms of blossom end rot in each plot. The blossom end rot incidence is expressed as a percentage of total fruits. The fruit firmness was recorded with the help of a penetrometer (Effigi, 11-mm probe). For this purpose, 5 fruits from each treatment were taken and penetration force was measured by gently inserting the probe into the equatorial region of the fruit. The readings for all 5 fruits were averaged to represent the corresponding treatments. The fruit juice was extracted from the fruits and the TSS levels were measured with a hand-held refractometer (KROSS HRN-16). The refractometer was first calibrated with distilled water to have a zero reading. Two drops per sample were added to the refractometer prism plate. The readings on the prism plate were noted to one decimal place. After each test, the prism plate was cleaned with distilled water and wiped with a soft tissue paper.

Results

Plant height and number of branches per plant

The mean plant height increased significantly with foliar application of $CaCl_2$ and borax either alone or in combination. The plant height increased from 77.07 cm in the control to a maximum of 86.60 cm with 0.6% $CaCl_2$ + 0.2% borax application, followed by 85.69 cm with 0.3% $CaCl_2$ + 0.2% borax (Table 1). The number of branches per plant was not significantly affected by the foliar application of $CaCl_2$ alone. However, borax, either alone or in combination with $CaCl_2$, resulted in a significant increase in the number of branches per plant The number of branches per plant increased from 5.37 in the control to 6.41 with 0.2% borax and to a maximum (7.21) with 0.6% $CaCl_2$ + 0.2% borax, followed by 6.60 with 0.3 $CaCl_2$ + 0.2% borax (Table 1).

Number of flowers and fruits per cluster

The number of flowers per cluster was not affected by application of $CaCl_2$ alone, but borax application resulted in a significant increase in the number of flowers per cluster. The number of flowers per cluster increased from 17.13 in the control to 30.32 with 0.2% borax application. The maximum number of flowers per cluster (32.36) was recorded with 0.6% $CaCl_2$ + 0.2% borax application. The difference among 0.2% or 0.4% borax applied alone and in combinations of 0.3% $CaCl_2$ + 0.2% borax and 0.6% $CaCl_2$ + 0.2% borax was not significant (Table 1). Foliar application of borax also significantly increased the number of fruits per cluster from 4.05 in the control to 6.32 with 0.4% borax. The combination of 0.6% $CaCl_2$ + 0.2% borax resulted in the maximum number (6.35) of fruits per cluster, though it was on par with 0.3% $CaCl_2$ + 0.2% borax and 0.2% or 0.4% borax applied alone (Table 1).

Number of fruits per plant

The number of fruits per plant increased significantly from 46.20 to 61.66 with 0.3% $CaCl_2$ application. It increased further to 78.24 and 82.44 with 0.2% and 0.4% borax application. However, the maximum number of fruits per plant (96.73) was recorded with 0.6% $CaCl_2$ + 0.2% borax.

Table 1. Influence of calcium chloride and borax application on vegetative and reproductive growth of tomato plants.

$CaCl_2$ and borax treatments	Plant height	Number of branches	Flowers per cluster	Fruits per cluster	Fruits per plant
Control	77.07 c	5.37 c	17.13 b	4.05 b	46.20 d
0.3% $CaCl_2$	80.96 b	5.39 c	17.81 b	4.79 b	61.66 c
0.6% $CaCl_2$	80.53 b	5.33 c	18.43 b	4.54 b	59.66 c
0.2% borax	82.07 b	6.410 b	30.32 a	5.38 ab	78.24 b
0.4% borax	81.39 b	6.40 b	30.27 a	6.32 a	82.84 b
0.3% $CaCl_2$ + 0.2% borax	85.69 a	6.60 ab	29.50 a	5.73 ab	91.02 a
0.3% $CaCl_2$ + 0.4% borax	84.73 a	6.02 b	30.77 a	5.89 a	93.89 a
0.6% $CaCl_2$ + 0.2% borax	86.60 a	7.21 a	32.36 a	5.96 a	96.73 a
0.6% $CaCl_2$ + 0.4% borax	83.95 a	6.13 bc	29.79 a	6.35 a	92.61 a
LSD at $\alpha = 0.05$	3.1030	0.717	2.727	1.119	7.149

Different letters within columns indicate statistical significance ($P < 0.05$).

Fruit weight and yield

The fruit weight of tomato increased significantly from 62.66 g in the control to 81.47 and 81.32 g with foliar application of 0.2% and 0.4% borax. The fruit weight increased to its maximum (96.33 g) with 0.6% $CaCl_2$ + 0.2% borax application, although it was on par with 0.3% $CaCl_2$ + 0.2% borax (89.69 g). The borax application also resulted in a significant increase in yield of tomato fruit as compared to both the control and plants treated with calcium chloride alone. However, the combination of $CaCl_2$ and borax (0.6% $CaCl_2$ + 0.2% borax) increased the yield to its maximum (21.33 t ha^{-1}), followed by 0.3% $CaCl_2$ + 0.2% borax (20.65 t ha^{-1}) (Table 2).

Fruit quality

The incidence of blossom end rot was the highest (17.56%) in the control and decreased significantly to 14.22% and 10.12% with 0.3% and 0.6% $CaCl_2$ application. The blossom end rot incidence was 14.72% and 14.21% with application of borax at 0.2% and 0.4%, which was significantly lower than the control but higher than 0.6% $CaCl_2$ (Table 2). The incidence of blossom end rot decreased to 8.49% with 0.3% $CaCl_2$ + 0.4% borax and declined further to 7.54% and 6.25% with 0.6% $CaCl_2$ + 0.2% borax and 0.6% $CaCl_2$ + 0.4% borax, respectively (Table 2).

The fruit firmness in control fruits (2.76) increased significantly to 2.21 and 3.26 kg cm^{-2} with foliar application of 0.3% $CaCl_2$. Application of borax as 0.2% and 0.4% solutions also resulted in significant increase in fruit firmness to 3.20 and 3.21 kg cm^{-2}, respectively. The maximum fruit firmness of 3.46 kg cm^{-2} was, however, recorded with 0.6% $CaCl_2$ + 0.2% borax application. The differences among fruit firmness of fruits receiving 0.3 % $CaCl_2$ + 0.2% borax, 0.3 % $CaCl_2$ + 0.4% borax, 0.6% $CaCl_2$ + 0.2% borax, and 0.6% $CaCl_2$ + 0.4% borax were nonsignificant (Table 2).

The TSS content of tomato fruit was not significantly affected by the application of $CaCl_2$ alone, but borax alone and $CaCl_2$ + borax increased it significantly. The application of 0.2% borax significantly increased the TSS to 5.47% as compared to 4.08% in the control. The combination of 0.3% $CaCl_2$ + 0.2% and 0.6% $CaCl_2$ + 0.2% increased the TSS to 5.92% and 6.10%; however, the difference between these treatments was not significant (Table 2).

Discussion

The foliar application of $CaCl_2$ alone increased plant height significantly but the number of branches per plant was not significantly affected. Application of borax, however, significantly increased the plant height as well as the number of branches per plant. The combined application of $CaCl_2$ and borax resulted

Table 2. Effect of calcium chloride and borax application on yield and quality of tomato.

$CaCl_2$ and borax treatments	Fruit weight (g)	Yield (t ha^{-1})	BER %	Fruit firmness (kg cm^{-2})	TSS
Control	62.66 c	13.21 c	17.56 a	2.76 c	4.08 d
0.3% $CaCl_2$	67.59 c	14.39 bc	14.22 b	3.21 b	4.16 d
0.6% $CaCl_2$	63.66 c	14.45 bc	10.12 c	3.26 b	4.05 d
0.2% borax	81.47 b	15.00 b	14.72 b	3.20 b	5.47 c
0.4% borax	81.32 b	15.56 b	14.21 b	3.21 b	5.33 c
0.3% $CaCl_2$ + 0.2% borax	89.69 a	20.65 a	10.26 c	3.40 a	5.92 ab
0.3% $CaCl_2$ + 0.4% borax	88.19 a	20.31 a	8.49 c	3.23 a	5.58 bc
0.6% $CaCl_2$ + 0.2% borax	96.33 a	21.33 a	6.25 d	3.46 a	6.10 a
0.6% $CaCl_2$ + 0.4% borax	87.42 a	19.62 a	7.54 d	3.43 a	5.67 bc
LSD at $\alpha = 0.05$	9.294	1.765	2.21	0.243	0.3574

Different letters within columns indicate statistical significance ($P < 0.05$).
BER = Blossom end rot.

in superior plant height and number of branches per plant as compared to either nutrient applied alone (Table 1). Both calcium and boron are required for the growth and development of plants (Bose and Tripathi 1996). Boron increased plant height and the number of branches of tomato plant by promoting root growth, which enhances nutrient absorption (Sathya et al. 2010). Deficiency of calcium and boron decreases plant height by decreasing mitotic activity in the terminal meristem (Nelson and Niedziela 1998). Thus, the application of calcium chloride and borax increases plant height (Dole and Wilkins 2005). Since boron enhances calcium metabolism, especially in the cell wall (Blevins and Lukaszewski 1998), the calcium and boron combinations were more effective than sole application in increasing the number of branches per plant (Asad et al. 2003).

Foliar application of borax alone or in combination with calcium chloride resulted in a significant increase in the number of flowers and fruits per cluster (Table 1). Boron nutrition regulates water absorption and carbohydrate metabolism (Haque et al. 2011). The application of boron enhances fruit set (Desouky et al. 2009) by delaying abscission of flowers (Smit and Combrink 2004). Thus, it is likely that the higher number of flowers per cluster could be due to sufficient levels of carbohydrates available for flower formation and fruit set in tomato (Smit and Combrink 2004).

While the number of fruits per plant increased significantly with $CaCl_2$ application, the increase was greater with borax (Table 1). The combination treatments resulted in further increase in the number of fruits per plant. The number of fruits per plant depends on the number of flowers and the ability of the plant to provide the nutrients required for growth and development. Since the application of boron increased the fruits per cluster (Desouky et al. 2009), it is likely that a higher number of fruits per plant will be observed with borax application. However, unlike the fruits per cluster, the number of fruits per plant was superior to the control with $CaCl_2$ application. Similarly, application of boron alone resulted in a lower number of fruits per plant as compared to the $CaCl_2$ + borax combination. This indicates that both calcium and boron are required for decreasing the abscission of flowers and fruits (Smit and Combrink 2004).

The fruit weight of tomato increased significantly with foliar application of 0.2% and 0.4% borax. However, the combination of both nutrients resulted in higher fruit weights. In a similar fashion, the yield of tomato increased significantly with borax application as well as with its combination with $CaCl_2$ (Table 2). The fruit growth and final yield depend on the continued supply of food material and water (Huett and Dettmann 1988). Since boron helps in the absorption of water and carbohydrate metabolism (Haque et al. 2011), its deficiency may cause sterility, small fruit size, and poor yield (Davis et al. 2003). It is interesting to observe that both calcium and boron application were less effective in increasing fruit size and yield as compared to combined treatments. This indicates that a critical balance between calcium and boron may determine the beneficial effects of these nutrients (Passam et al. 2007; Tariq and Mote 2007).

The application of $CaCl_2$ resulted in a significant decline in blossom end rot incidence and the decline was greater with a high (0.6%) $CaCl_2$ concentration. Application of borax also resulted in significantly lower blossom end rot incidence than in the control, but this rate was higher than with 0.6% $CaCl_2$ (Table 2). However, the combined application of 0.6% $CaCl_2$ + 0.2% borax resulted in the lowest blossom end rot incidence (Table 2). The blossom end rot of tomato fruit is a physiological disorder resulting from calcium deficiency (Del-Amor and Marcelis 2003). It reduces fruit quality and market value (Taylor et al. 2004). The blossom end rot incidence can be aggravated by the deficiency of other nutrients such as NH_4-N, K, and Mg (Navarro et al. 2005). Boron deficiency is also a widespread problem that decreases yield and fruit quality. Boron deficiency results in cracking of fruit, which may encourage blossom end rot. Smit and Combrink (2004) reported that boron application enhances the uptake of Ca, Mg, Na, and Zn, and hence it may decrease blossom end rod by increasing calcium metabolism in the tomato fruit (Davis et al. 2003). Boron may also promote the cell wall structure by enhancing cell wall cross-linking (Blevins and Lukaszewski 1998) and thus decreasing the blossom end rot incidence.

The fruit firmness increased with foliar application of $CaCl_2$ and borax but the maximum fruit firmness was recorded with 0.6% $CaCl_2$ + 0.2% (Table 2). Fruit firmness is an important quality in fruit. Both calcium and boron are essential for cell wall structure and function (Blevins and Lukaszewski 1998; Davis et al. 2003). The increased fruit firmness with increasing $CaCl_2$ and borax and with their combination indicates that both Ca and B may enhance fruit firmness (Smit and Combrink 2004). However, higher fruit firmness was observed with combined application of $CaCl_2$ and borax. Since boron not only promotes calcium metabolism in cell walls (Lukaszewski 1998) but may also promote cell wall integrity as well as delay cell wall degradation (Ryden et al. 2003; Lester and Grusak 2004), the combined treatment resulted in greater fruit firmness than Ca or B alone.

The TSS content of tomato fruit increased significantly with 0.2% borax application. The maximum TSS content was recorded with 0.6% $CaCl_2$ + 0.2% borax application, which was on par with 0.3% $CaCl_2$ + 0.2% borax (Table 2). The TSS content of the fruits is a major quality parameter (Ali et al. 2004). Preharvest calcium and boron application may affect the chemical composition of fruits (Mahajan and Sharma 2000; Sathya et al. 2010). No increase in TSS was observed with the application of $CaCl_2$ alone, but borax alone or $CaCl_2$ + borax resulted in a significant increase in the TSS contents of tomato fruit. The TSS contents of tomato fruit have been shown to correlate with available boron and are increased by both soil and foliar application of boron (Sathya et al. 2010). This indicates that the interaction of calcium and boron may be more critical for the TSS contents of tomato fruit (Hasan and Jana 2000).

It can be concluded from these results that exogenous application of $CaCl_2$ on tomato plants results in a significant increase in plant height, fruits per plant, and fruit firmness as well as a decrease in blossom end rot incidence. Application of borax was more effective in increasing the number of branches, flowers per cluster, fruits per cluster, fruit weight, and TSS content of the fruit. For the various parameters studied, the combination of $CaCl_2$ and borax resulted in significantly superior performance compared to either of the chemicals applied alone.

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