Management of Anthracnose in Common Bean by Foliar Sprays of Potassium Silicate, Sodium Molybdate, and Fungicide

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Abstract

This study aimed to determine whether foliar sprays of potassium silicate (KSi), sodium molybdate (NaMo), or a combination of both (KSi + NaMo), with or without the fungicide azoxystrobin (Azox), could reduce anthracnose symptoms and, consequently, increase yield. Two two-by-four factorial experiments, consisting of untreated or fungicide treated, as well as sprays of KSi, NaMo, KSi + NaMo, and no spray (control), were arranged in a randomized block design with three replications. Treatments were as follows: treatment 1, KSi spray; treatment 2, NaMo spray; treatment 3, KSi + NaMo spray; treatment 4, Azox spray; treatment 5, Azox + KSi spray; treatment 6, Azox + NaMo spray; treatment 7, Azox + KSi + NaMo spray; and treatment 8, control (no KSi, NaMo, or Azox). The KSi, NaMo, and Azox treatments were sprayed at the rates of 35 g/liter, 90 g/ha, and 120 g a.i./ha, respectively. The KSi was applied at 27, 40, and 55 days after sowing (das). The NaMo was sprayed only at 27 das whereas the fungicide was sprayed at 27, 40, and 55 das. Plants were inoculated with Colletotrichum lindemuthianum at 23 das. Azox reduced the mean area under disease progress curve (AUDPC) by 63% and mean yield was increased by 150%. Similarly, the mean AUDPC was reduced by 29, 14, and 41% with KSi, NaMo, and KSi + NaMo sprays, respectively, while mean yield increased by 13, 20, and 47%, with KSi, NaMo, or KSi + NaMo sprays, respectively. The variables leaf area index (LAI), leaf area index duration (LAD), healthy leaf area duration (HAD), and healthy leaf area absorption (HAA) were significantly increased as a result of NaMo spray. The results of the present study support the novel possibility of using a foliar spray of KSi in association with NaMo to decrease anthracnose symptoms in bean plants and, consequently, achieve greater yield.

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diseases are all Mo dependent (22). The exact role of Mo in resistance to diseases has yet to be determined; however, it is known that a decrease in the Mo concentration in the soil solution can decrease host resistance to diseases by affecting the production of NR, an enzyme that contains two Mo atoms, which is required to convert nitrates into proteins (17). Reduction in the activity of Mo-dependent enzymes affects plant growth, particularly with regard to nitrogen metabolism, and also the synthesis of abscisic acid and indole-3-butyric acid (17). Mo has been reported to reduce the symptoms of Verticillium wilt on tomato plants (7,24) and, according to Hal-sall (13), Mo inhibits the production of zoospores by Phytophthora cinnamomi and P. drechsleri. The population of Rotylenchulus reniformis on the roots of castor bean plants was decreased in soil amended with Mo (14). Jesus Júnior et al. (15) showed that one application of sodium molybdate (NaMo) to bean plants grown in a Mo-deficient soil at 25 days after sowing reduced angular leaf spot severity and increased the area of healthy leaves, photosynthesis, and yield. The combination of fungicide, applied once or twice, during the interval from 25 to 45 days after sowing, with NaMo at 25 days increased plant growth and reduced the angular leaf spot severity (15).

To the best of our knowledge, however, information in the literature regarding the effects of Si and Mo, and the combination of these elements in association with fungicide applications, on the reduction of anthracnose progress is lacking. Therefore, this study aimed to determine whether foliar application of KSi, NaMo, or a combination of both salts, with or without a fungicide, could reduce anthracnose symptoms and, consequently, increase yield due to better plant growth.

Materials and Methods

Inoculum production. Isolate 81-538 (race 81) of C. lindemuthianum, obtained from the Bean Fungus Collection Culture from the Department of Biology, Viçosa Federal University, was used in this study. The isolate was preserved on strips of filter paper placed into glass tubes containing silica gel at 4°C. Pieces of filter paper with fungal mycelia were transferred to petri dishes containing potato-dextrose-agar (PDA). For inoculum production, PDA plugs (5 mm in diameter) containing fungal mycelia were placed on the surface of sterilized bean pods with their bases inserted into glass tubes containing water/agar (3%, vol/vol). The tubes were stored in a growth chamber (MA-835/2106UR, Marconi) at 25°C with a photoperiod of 12 h of light and 12 h of darkness for 10 days. After acervuli were formed on pods, distilled water was added to the tubes to obtain a conidial suspension. The suspension was filtered through double cotton gauze and adjusted to a concentration of 1.2 × 10^6 conidia/ml using a Neubauer-counting chamber. Gelatin 1% (wt vol⁻¹) was added to the suspension to facilitate the adhesion of conidia to the leaf surface.

Plant growth, treatments, and inoculation with C. lindemuthianum. Two field experiments were conducted in an experimental area at Viçosa Federal University in Viçosa, Brazil, which is located in the southeastern region of Minas Gerais State at 20°44′44″S, 42°50′59″W, and 661 m above sea level. The first experiment was performed from March to May 2009 and the second from September to December 2009. The chemical characteristics of the red oxisol of the experimental area were as follows: pH (H₂O), 5.4; P, 17 mg dm⁻³; K, 80 mg dm⁻³; Ca²⁺, 3.41 cmol dm⁻³; Mg²⁺, 0.44 cmol dm⁻³; and Al³⁺, 0.0 cmol dm⁻³. The concentration of Mo in the soil was 0.2 mg/kg of soil, which is below the desirable level required by bean plants of 0.5 to 5 mg/kg of soil (12). In total, 10 plants (‘Pêrola’, a ‘Carioca’ type susceptible to anthracnose) were kept per linear meter. The plots were maintained using conventional practices for bean crops, including fertilization before sowing based on the results of the soil chemical analysis. The soil was fertilized with nitrogen, P₂O₅, and K₂O at 20, 70, and 40 kg/ha, respectively, and the plants received insecticidal spray, weeding, and sprinkler irrigation as needed. Each experimental plot consisted of five rows of 5 m in length, each spaced at 0.5 m, corresponding to a total area of 12.5 m². The distance between plots was 1 m. Each experiment was a two-by-four factorial experiment arranged in a randomized block design with three replications. The first factor was azoxystreptomycin (Azox) or no Azox application and the second factor consisted of the applications of KSi, NaMo, KSi + NaMo, and a control (no spray). In summary, the treatments were as follows: treatment 1, KSi; treatment 2, NaMo; treatment 3, KSi + NaMo; treatment 4, Azox; treatment 5, Azox + KSi; treatment 6, Azox + NaMo, treatment 7, Azox + KSi + NaMo; and treatment 8, control (no spray). To avoid interplot interference, only the three central rows of each plot were used for all assessments. For these three rows, plants located at 0.5 m from plot ends were not used in the assessments. The source of Si used to spray plants was KSi (26.7% SiO₂ and 13.1% K₂O; FertiSil; PQ Silicas Brazil) at the rate of 35 g/liter, corresponding to 14 kg/ha. Mo was applied as NaMo (Sigma-Aldrich) at the rate of 90 g/ha. The fungicide Azox (Amistar 50 WG; Syngenta) was applied at the rate of 120 g a.i./ha. Treatments were applied to all five rows of each plot but timing of application varied. KSi was sprayed at 20, 27, 40, and 55 days after sowing (das), corresponding to the plant growth stages of V3, V4, R5, and R6, respectively (40). Plants were sprayed with NaMo at 27 das for maximum Mo uptake by the bean leaves, and the fungicide was applied at 27, 40, and 55 das. Treatments were applied in approximately 500 ml of solution with a CO₂ pressurized backpack sprayer at two bars (3.1 × 10⁵ Pa) with Teejet 110.03 nozzles. Plants from all rows of each plot were inoculated with a conidial suspension of C. lindemuthianum (approximately 500 ml of suspension per plot) using a CO₂ pressurized backpack sprayer (3.1 × 10⁵ Pa) with Teejet 110.03 nozzles at 23 das (growth stage V3).

Assessment of anthracnose severity. Anthracnose severity was assessed weekly on the leaves of plants starting at 35 das using a diagrammatic scale, with severity values of 0.1 to 24% (10). Data for severity over time were used to calculate the area under disease progress curve (AUDPC) according to Shaner and Finney (34).

Determination of grain yield. Production of shelled bean (g/plant) was determined for the plants from the three central rows of each plot, with a total area of 6 m² and containing 120 plants. The seeds were weighed at 12% moisture content.

Determination of integral variables. LAI, expressed in m²/m², was determined by multiplying the average leaf area of 20 plants using LI-3100C leaf area meter (considering 20 plants/m²). The HLAI was obtained based on the LAI and expressed in m²/m² according to Waggoner and Berger (39). Leaf area index duration (LAD), expressed in days, was calculated as described by Watson (40). The HAD, expressed in days, was calculated according to Waggoner and Berger (39). The LAD was obtained through the integration of the time values of LAI and expressed in days, as defined by Watson (40). Starting at 35 das, plants from each plot were assessed weekly using destructive sampling to determine the variables described above. The leaves were passed through an area meter (LI-3100C; LI-COR Inc.) to determine leaf area prior to drying. The RI, expressed as MJ/m², was calculated according to Bergamin Filho et al. (2) using a k factor of 0.7 for a bean crop (28). The HRI, as expressed in MJ/m², was obtained according to Bergamin Filho et al. (2). The HAA, as expressed in MJ/m², for each plant was calculated according to Waggoner and Berger (39). The RUE, expressed in g/MJ, was estimated by a regression analysis between the accumulated plant dry weight (g/m²) and the sum of HAA weekly (MJ/m²), according to Sinclair and Muchow (35). Starting at 35 das, the plants were assessed weekly for these variables, without destructive sampling, using a portable open-system infrared gas analyzer (LI-6400; LI-COR Inc.).
no spray (control) alone or in combination with Azox on all variables studied was determined according to Tukey’s test.

**Results**

**AUDPC and grain yield.** Fungicide applications reduced disease severity and resulted in greater yields in both experiments. In the first experiment, AUDPC was 67.7% lower for plants sprayed with Azox fungicide compared with nonsprayed plants (Table 1) whereas, in the second, AUDPC decreased by 58.7% with fungicide spray (Table 2). Grain yield was higher in plants sprayed with fungicide, with an increase of 148.9 and 152.2% compared with the nonsprayed plants in experiments 1 and 2, respectively (Table 1).

**Variables related to plant growth.** Fungicide applications increased all the variables related to plant growth in both experiments. In the first experiment, the LAI, HLAI, LAD, and HAD decreased disease severity and resulted in greater yields in both experiments.

**Table 1.** Area under anthracnose progress curve (AUDPC), leaf area index (LAI, m²/m²), healthy leaf area index (HLAI, m²/m²), leaf area index duration (LAD, days), healthy leaf area duration (HAD, days), intercepted radiation of the healthy leaf area (HRI, MJ/m²), healthy leaf area absorption (HAA, MJ/m²), intercepted radiation (RI, MJ/m²), radiation use efficiency (RUE, g/MJ), and grain yield (Yield, g/plant) on bean plants (‘Pérola’) inoculated with *Colletotrichum lindemuthianum* and sprayed (+F) or nonsprayed (–F) with fungicide in experiment 1

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>AUDPC</th>
<th>LAI</th>
<th>HLAI</th>
<th>LAD</th>
<th>HAD</th>
<th>Physiological variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>–F</td>
<td>326.17</td>
<td>2.01</td>
<td>1.92</td>
<td>88.76</td>
<td>85.00</td>
<td>9.53</td>
</tr>
<tr>
<td>+F</td>
<td>105.54</td>
<td>2.20</td>
<td>2.17</td>
<td>97.28</td>
<td>95.69</td>
<td>10.07</td>
</tr>
<tr>
<td>MS</td>
<td>292.061.16*</td>
<td>0.21*</td>
<td>0.37*</td>
<td>435.71*</td>
<td>685.97*</td>
<td>1.75*</td>
</tr>
<tr>
<td>CV (%)</td>
<td>14.15</td>
<td>7.88</td>
<td>7.78</td>
<td>7.38</td>
<td>7.46</td>
<td>3.01</td>
</tr>
</tbody>
</table>

* Asterisk (*) indicates significant at \( P = 0.05 \) by \( F \) test. MS = mean square and CV = coefficient of variation.

**Table 2.** Area under anthracnose progress curve (AUDPC), leaf area index (LAI, m²/m²), healthy leaf area index (HLAI, m²/m²), leaf area index duration (LAD, days), healthy leaf area duration (HAD, days), intercepted radiation of the healthy leaf area (HRI, MJ/m²), healthy leaf area absorption (HAA, MJ/m²), intercepted radiation (RI, MJ/m²), radiation use efficiency (RUE, g/MJ), and grain yield (Yield, g/plant) on common bean plants (‘Pérola’) inoculated with *Colletotrichum lindemuthianum* and sprayed (+F) or nonsprayed (–F) with fungicide in experiment 2

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>AUDPC</th>
<th>LAI</th>
<th>HLAI</th>
<th>LAD</th>
<th>HAD</th>
<th>Physiological variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>–F</td>
<td>53.30</td>
<td>2.32</td>
<td>2.28</td>
<td>64.01</td>
<td>62.75</td>
<td>17.66</td>
</tr>
<tr>
<td>+F</td>
<td>22.11</td>
<td>2.51</td>
<td>2.48</td>
<td>68.82</td>
<td>68.12</td>
<td>18.42</td>
</tr>
<tr>
<td>MS</td>
<td>9,511.99*</td>
<td>0.19*</td>
<td>0.25*</td>
<td>138.52*</td>
<td>172.96*</td>
<td>3.41*</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12.96</td>
<td>4.97</td>
<td>4.70</td>
<td>5.30</td>
<td>5.20</td>
<td>3.39</td>
</tr>
</tbody>
</table>

* Asterisk (*) indicates significant at \( P = 0.05 \) by \( F \) test. MS = mean square and CV = coefficient of variation.

**Table 3.** Effects of potassium silicate (KSi), sodium molybdate (NaMo), KSi + NaMo, and no spray (control) applied to bean foliage alone or in combination with fungicide (–F and +F, respectively) on the area under anthracnose progress curve (AUDPC) and on the growth variables leaf area index (LAI, m²/m²), healthy leaf area index (HLAI, m²/m²), leaf area index duration (LAD, days), and healthy leaf area duration (HAD, days) in experiment 1

<table>
<thead>
<tr>
<th>Treatments</th>
<th>AUDPC</th>
<th>LAI</th>
<th>HLAI</th>
<th>LAD</th>
<th>HAD</th>
<th>Physiological variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungicide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>–F</td>
<td>382.4 Aa</td>
<td>137.7 B</td>
<td>1.64 Ab</td>
<td>1.90 Bb</td>
<td>1.56 Ab</td>
<td>1.86 Bb</td>
</tr>
<tr>
<td>KSi</td>
<td>303.2 Ab</td>
<td>93.26 Bbc</td>
<td>1.81 Ab</td>
<td>2.02 Ab</td>
<td>1.72 Ab</td>
<td>1.99 Bb</td>
</tr>
<tr>
<td>NaMo</td>
<td>335.8 Aab</td>
<td>124.5 Bb</td>
<td>2.25 Aa</td>
<td>2.32 Aab</td>
<td>2.13 Aa</td>
<td>2.28 Aab</td>
</tr>
<tr>
<td>KSi + NaMo</td>
<td>283.0 Ab</td>
<td>66.61 Bc</td>
<td>2.35 Aa</td>
<td>2.57 Aa</td>
<td>2.26 Aa</td>
<td>2.54 Aa</td>
</tr>
<tr>
<td>MS</td>
<td>8,312.16*</td>
<td>0.60*</td>
<td>0.59*</td>
<td>1,240.14*</td>
<td>1,229.82*</td>
<td>0.0003ns</td>
</tr>
<tr>
<td>CV (%)</td>
<td>10.26</td>
<td>5.60</td>
<td>5.60</td>
<td>5.40</td>
<td>5.50</td>
<td></td>
</tr>
</tbody>
</table>

* For each variable, means within a row followed by the same uppercase letter or means within a column followed by the lowercase same letter are not significantly different (\( P = 0.05 \)) as determined by Tukey’s test. Asterisk (*) indicates significant at \( P = 0.05 \) by \( F \) test. MS = mean square and CV = coefficient of variation.

**Table 4.** Single degree-of-freedom contrasts for comparisons of the treatments potassium silicate (KSi), sodium molybdate (NaMo), and KSi + NaMo on area under anthracnose progress curve (AUDPC), leaf area index (LAI, m²/m²), healthy leaf area index (HLAI, m²/m²), leaf area index duration (LAD, days), healthy leaf area duration (HAD, days), intercepted radiation of the healthy leaf area (HRI, MJ/m²), healthy leaf area absorption (HAA, MJ/m²), intercepted radiation (RI, MJ/m²), radiation use efficiency (RUE, g/MJ), and grain yield (Yield, g/plant) in experiment 1

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>AUDPC</th>
<th>LAI</th>
<th>HLAI</th>
<th>LAD</th>
<th>HAD</th>
<th>Physiological variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>–KSi vs. +KSi</td>
<td>11,468.22**</td>
<td>0.06ns</td>
<td>0.06*</td>
<td>96.95ns</td>
<td>108.60ns</td>
<td>0.24*</td>
</tr>
<tr>
<td>–NaMo vs. +NaMo</td>
<td>2675.75*</td>
<td>0.79**</td>
<td>0.73**</td>
<td>1,613.56**</td>
<td>1,514.70**</td>
<td>2.89**</td>
</tr>
<tr>
<td>–KSi –NaMo vs. +KSi +NaMo</td>
<td>21,809.50**</td>
<td>1.40**</td>
<td>1.42**</td>
<td>2,796.85**</td>
<td>2,868.44**</td>
<td>4.50**</td>
</tr>
</tbody>
</table>

* Asterisks * and ** = significant at \( P = 0.05 \) and 0.01, respectively, by \( F \) test; ns = not significant; – and + = nonsprayed and sprayed, respectively.

Similarly, applications of KSi, NaMo, and NaMo + KSi reduced disease severity, although not as effectively as an application of Azox, and yields were greater than that of the untreated control. In experiment 1, applications of KSi, NaMo, and NaMo + KSi reduced AUDPC by 23.8, 11.5, and 32.8%, respectively (Tables 3 and 4), while grain yield increased by 6.2, 11.7, and 46.1%, respectively (Tables 4 and 5). In experiment 2, AUDPC decreased by 34.5, 17.4, and 50.9% and grain yield increased by 20.9, 29.2, and 48.7% for the plants sprayed with KSi, NaMo, and NaMo + KSi, respectively (Tables 6 and 7).
variables were higher by 9.45, 13.0, 9.6, and 12.6%, respectively, for the plants sprayed with fungicide compared with the nonsprayed plants (Table 1) whereas, in the second, LAI, HLAI, LAD, and HAD increased by 7.8, 8.8, 7.5, and 8.6%, respectively, with fungicide spray (Table 2). Regardless of the experiment, LAI, LAD, and HAD were not affected by the KSi spray (Tables 4 and 7). HLAI was affected by KSi spray only in experiment 1 (Table 4). The LAI values increased by 29.1 and 39.0% in experiment 1 (Tables 3 and 4) and by 32.5 and 44.4% in experiment 2 (Tables 6 and 7) for plants sprayed with NaMo and KSi + NaMo + KSi, respect-
tively, compared with the nonsprayed plants. HLAI increased by 8.5, 29.0, and 40.4% with the KSi, NaMo, and NaMo + KSi sprays, respectively, in experiment 1 (Tables 3 and 4) and by 32.4 and 46.1% for the plants sprayed with NaMo and NaMo + KSi, respectively, compared with the nonsprayed plants (Tables 6 and 7). LAD increased by 29.6 and 39.0% and HAD by 29.7 and 41.0% for the plants sprayed with NaMo and NaMo + KSi, respectively, in experiment 1 (Tables 3 and 4) and LAD by 28.8 and 42.7% and HAD by 29.0 and 44.2% for the plants sprayed with NaMo and NaMo + KSi, respectively, in experiment 2 (Tables 6 and 7).

Variables related to bean physiology. Fungicide applications increased all the variables related to bean physiology. RI and HRI increased by 4.3 and 5.7%, respectively, in experiment 1 (Table 1) and by 4.1 and 4.30%, respectively, in experiment 2 (Table 2) and for the plants treated with fungicide compared with the nonsprayed plants. RI was not affected by KSi in experiments 1 and 2 (Tables 4, 5, 7, and 8), while the HRI was not affected by KSi only in experiment 2 (Tables 7 and 8). RI significantly increased by 10.1 and 12.4% in experiment 1 (Tables 4 and 5) and by 15.9 and 19.0% in experiment 2 (Tables 7 and 8) for the plants sprayed with NaMo and NaMo + KSi, respectively. HRI significantly increased by 3.1, 10.7, and 13.4% in experiment 1 for the plants sprayed with KSi, NaMo, and NaMo+KSi, respectively (Tables 4 and 5) and by 14.3 and 17.0% in experiment 2 for the plants sprayed with NaMo and NaMo + KSi, respectively (Tables 7 and 8). HAA and RUE significantly increased by 5.4 and 133.3% in experiment 1, respectively, and by 3.9 and 150.0%, respectively, with the fungicide treatment (Table 1). HAA significantly increased by 2.8, 10.9, and 13.5% in experiment 1 (Tables 4 and 5) and by 2.8, 12.7, and 15.9% in experiment 2 (Tables 7 and 8) for the plants sprayed with KSi, NaMo, and NaMo + KSi, respectively. In experiment 1, RUE was not affected by the KSi spray (Tables 4 and 5) whereas, in experiment 2, RUE significantly increased by 14.3, 12.5, and 25.0% for the plants sprayed with KSi, NaMo, and NaMo + KSi, respectively (Tables 7 and 8). RUE significantly increased by 1.6 and 31.3% for the plants sprayed with NaMo and NaMo + KSi, respectively, in experiment 1 (Tables 4 and 5).

Discussion

Si, either applied to the soil or as a foliar spray, reduces the intensity of diseases of economic importance in crops such as barley, corn, cucumber, grape, rye, rice, soybean, and strawberry (5,31,32). There are also a few reports showing the involvement of Mo in reducing the intensity of diseases on bean and tomato (7,15,24). To the best of our knowledge, however, no study on the bean–C. lindemuthianum pathosystem to date has investigated whether Si and Mo and their combination could increase host resistance to anthracnose. The present study shows that foliar application of KSi in combination with NaMo or in combination with a foliar fungicide could be an effective strategy for the management of anthracnose, resulting in greater yield. The foliar spray of KSi in combination with NaMo reduced the AUDPC. Similarly, an application of KSi alone reduced anthracnose symptoms and, consequently, AUDPC, resulting in greater yield. Foliar applications of KSi have been used successfully in such crops as bean, which has a poor capacity to take up Si from the soil solution and translocate it to the shoots (21). Moraes et al. (25) reported that a foliar spray of sodium silicate to bean plants decreased the AUDPC by 62.4% whereas a KSi application reduced angular leaf spot severity on bean plants by an average of 36% (32). In the present study, foliar application of KSi resulted in satisfactory anthracnose control, possibly due to the formation of a physical barrier as a result of the deposition of Si on the leaf surface or the osmotic effect of silicate sprayed onto the leaves. Anthracnose severity on plants from the control treatment reached 20.5 and 7.9%, respectively, in experiments 1 and 2. These values are considered quite high because the highest severity value in the diagrammatic scale used is 24%. Considering that the same cultivar was used in experiments 1 and 2 and plants were inoculated with the same isolate of C. lindemuthianum and at the same conidial concentration, the difference in the amount of disease between experiments was exclusively due to the environmental conditions. In Brazil, anthracnose is more severe on plants grown during low-temperature conditions (37), as was the case for experiment 1 that was carried out during the fall.

The application of NaMo decreased AUDPC, possibly because of its direct effect on C. lindemuthianum, thus increasing yield. As a heavy metal, Mo causes the denaturation of proteins and negatively affects lytic enzymes and nonselective toxins produced by pathogens (11), including C. lindemuthianum. Thus, contact of the C. lindemuthianum conidia produced from multiple cycles of the pathogen during the crop season with the NaMo solution could have affected their viability, growth, and further host tissue penetration, therefore decreasing anthracnose severity. It is also plausible that Mo may mediate some mechanisms of host defense against anthracnose, which merits further investigation.

Fungicide spray reduced the impact of anthracnose on yield and contributed to greater LAI, HLAI, LAD, HAD, HRI, and HAA and, consequently, was directly linked to better plant growth. A high yield can also be linked to the positive relationship of Mo with the physiological and host growth variables evaluated in the present study. The values for the physiological variables HAA, HRI, RI, and RUE, as well as those related to host growth, LAI, HLAI, LAD, and HAD, were greatly enhanced after fungicide spraying. Within this context, fungicide provided substantial control of anthracnose, sufficient to account for the improved plant growth and yield. Foliar application of KSi had no significant effect on the variables LAI, LAD, and HAD because bean plants are not able to uptake much Si through foliage (34). Thus, it is likely that KSi is related to the reduction in anthracnose severity by its direct effect on the pathogen’s development and not on plant growth. Bowen et al. (3) reported that the layers of KSi covering the cuticle of vine leaves prevented both germination and the penetration of ascospores of Uncinula necator; in contrast, the fungus grew without being impeded on the leaf areas that were not covered. Foliar application of KSi mainly increased yield through the decrease in anthracnose severity, corroborating the results of Rodrigues et al. (32), who obtained an increase in bean yield from 30 to 43% with foliar application of KSi for angular leaf spot.

The values for the variables LAI, HLAI, LAD, HAD, HRI, HAA, and RUE were higher on the plants sprayed with NaMo, reflecting a positive effect of this micronutrient on growth and yield. A plausible explanation for a gain in yield due to NaMo spraying may be the role played by Mo in the activity of the enzymes NR and nitrogenase, both involved in nitrogen fixation (6). Jesus Júnior et al. (15) reported an increase of approximately 17% in seed yield upon NaMo spraying onto bean plants with angular leaf spot symptoms. The increase in yield was attributed to the reduction in disease severity and to the involvement of Mo in nitrogen metabolism, helping to increase the plant dry weight (36,38).

The results of the present study evoke a novel possibility of using foliar application of KSi in association with NaMo to reduce anthracnose severity on bean plants and, consequently, achieve greater gains in yield due to improved plant growth.

Literature Cited


