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PAPAYA (*CARICA PAPAYA*) TRANSPLANT GROWTH IS AFFECTED BY A *TRICHODERMA*-BASED STIMULATOR

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Abstract. **Research was conducted to determine the effect of a *Trichoderma*-based plant stimulator (TBS) on papaya seedling growth. Papaya seedlings were grown from seed in 0.5-liter Styrofoam containers filled with a commercial substrate (30% sphagnum peat moss, 20% perlite, 50% vermiculite). TBS was applied as a drench at the rates of 0, 62.5, 125, 250, and 500 million conidia per seedling (MCS) at sowing, at seedling emergence, at 1 week after emergence (WAE), or 2 WAE. The variables evaluated were time from sowing to seedling emergence, shoot height, concentration of nitrogen in nitrate ([N-NO_3]) and potassium ([K^+]) in leaf sap, leaf area, root dry weight, shoot dry weight, and time from emergence to readiness for transplanting. When TBS was applied 2 WAE, there were no significant effects on the variables evaluated. TBS applied at sowing did not significantly affect time to emergence. When applied at sowing, at emergence, and 1 WAE, all the other variables measured were affected to the same extent by a given TBS rate. At the rates of 250 to 500 MCS, [N-NO_3] in leaf sap increased by 30%, [K^+] in leaf sap increased by 22-25%, shoot dry weight increased by 28%, shoot height increased by 18%, root dry weight increased by 38%, leaf area increased by 22%, and time to readiness for transplanting was reduced by 10 days, as compared to control plants. These results indicate that TBS may be useful in increasing several growth attributes in papaya seedlings and in accelerating papaya transplant production.**

Papaya (*Carica papaya*) is grown commercially in many tropical and subtropical regions, including Florida. In 2003, global production of commercial papaya was estimated at approximately 10 million t (FAO, 2004). That year, papaya production in the US was concentrated in Hawaii and the US Pacific Islands (1012 ha, ≈2500 acres), Florida (134 ha, ≈330 acres), Puerto Rico (150 ha, ≈370 acres), and the US Virgin Islands.

Transplants are commonly used to establish commercial papaya, to offset the cost of expensive certified seed and to avoid strong weed interference in the first two months after the emergence of papaya seedlings. Papaya transplants are considered adequate to be planted in the field when the shoot is at least 20 cm in height, the stem is about 1 cm in diameter, and the plant has at least four true leaves, which usually takes 35 to 45 d after emergence (Morales-Payan, 1998; Nishina et al., 2000). The time to produce adequate papaya transplants may be affected by numerous factors, including cultivar, substrates, mineral nutrition, and plant regulators (Morales-Payan and Stall, 2003; Nishina et al., 2000; Palmer-Rannie et al., 2002).

Trichoderma spp. are soil fungi known to suppress the growth of pathogenic soil fungi such as such as *Rhizoctonia solani*, *Fusarium* spp., *Pythium* spp., and *Sclerotium rolfsii*, among others (DeMarco et al., 2004; Henselova, 2002; Khan et al., 2004; Rao and Kulkarni, 2003; Thornton, 2004). There are several commercial products for horticultural use based on *Trichoderma* that can be applied to plant materials and/or to the soil. Because of their natural origin, and because they are innocuous to humans, plants, birds, fish, and other ani-

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mals, *Trichoderma*-based products are considered suitable for organic cropping systems.

Trichoderma spp. have also been shown to stimulate plant growth in sweet corn (*Zea mays*), cucumber (*Cucumis sativus*), cabbage (*Brassica oleracea*), lettuce (*Lactuca sativa*), potato (*Solanum tuberosum*), tomato (*Lycopersicon esculantum*), carrot (*Daucus carota*), cotton (*Gossypium* spp.), beans (*Phaseolus vulgaris*), and peas (*Pisum sativum*), among other crops (Björkman et al., 1998; Harman and Björkman, 1998; Khan et al., 1997; Ousley et al., 1994; Rabeendran et al., 2000; Yossen et al., 2003). Although *Trichoderma* exists in nature, exogenous applications seem to be necessary in horticultural operations to increase its crop stimulation effect to desirable levels. The mechanism of crop growth stimulation attributed to *Trichoderma* is not well understood, but it has been suggested that it is triggered by growth-promoting metabolites excreted by these fungi around the plant root system (Chang et al., 1986; Windham et al., 1986), and/or is due to increased nutrient availability in the root zone caused by *Trichoderma* metabolites (Altomare et al., 1999). Björkman et al. (1998) reported that root growth was 66% higher in stressed sweet corn plants colonized by *Trichoderma harzianum* than in plants not colonized by the fungus, and that the effects might be partially due to reversal of lipid and membrane protein oxidation.

Documented research with *Trichoderma* in papaya is limited, contradictory, and focused on disease suppression rather than growth stimulation. In India, Khan et al. (1997) found that soil applications of *Paecilomyces lilacinus* and *T. harzianum* suppressed the nematode/fungus complex *Meloidogyne incognita/Fusarium solani* in papaya, significantly increasing plant growth. In contrast, Vawdrey et al. (2002) tested *Trichoderma* soil amendments to suppress *Phytophthora* root rot in papaya in Australia, and did not find significant disease reduction. The objective of this research was to determine the effect on a *Trichoderma*-based formulation on the growth of papaya seedlings for transplants.

Materials and Methods

The experiment was conducted in 2003 in Gainesville, Fla. Maximum and minimum temperatures during the experiment were 29.6 °C and 22.4 °C, respectively, and average photosynthetically active radiation (PAR) at noon was approximately 1670 µmol m^{-2} s^{-1}. Transplants of 'Red Lady' papaya were grown from seed on 0.5-L Styrofoam containers filled with a commercial substrate (30% sphagnum peat moss, 20% perlite, 50% vermiculite). Irrigation was provided daily (100 mL per container per day). Seedlings were fertilized with a total of 0.75 g of N, P, and K per container. Remedial disease or pest management was not necessary during this research.

A commercial formulation of *Trichoderma* (2:3 mixture of *T. harzianum* and *T. koningii*) (TBS) was applied as a soil drench at sowing, at emergence, 1 week after emergence (WAE), or 2 WAE, at the rates of 0, 62.5, 125, 250, and 500 million conidia per seedling (MCS). Each treatment (time of application by rate) was applied to 10 seedlings (10 containers), which were distributed in a completely randomized block design. The effect of TBS rates on the time from sowing to seedling emergence was determined. Shoot height was determined weekly after emergence for 7 weeks, and the concentrations of nitrogen in nitrate and potassium ([N-NO_3] and [K^+]) in leaf sap, leaf area, root dry weight, and shoot dry weight were determined 7 WAE. The time from emergence to field-ready condition was also determined. Papaya transplants were considered to be ready for field transplanting when the shoot was at least 20 cm in height, the stem was at least 1 cm in diameter, and the plant had at least four true leaves (Morales-Payan, 1998; Nishina et al., 2000). Leaf area was determined using ASSESS/Scanner (APS, St. Paul, Minn.), and ([N-NO_3] and [K^+] were determined using specific ion meters (Spectrum Technologies, Plainfield, Ill.). Resulting data were subjected to analysis of variance and regression at the 5% significance level (StatSoft, 1997).

Results and Discussion

The effects of TBS on the variables evaluated were rate and time of application-dependent. When TBS was applied at sowing, there were no significant effects on the time from sowing to the emergence of papaya seedlings. When TBS was applied at sowing, at emergence, or at 1 WAE, shoot height, [N-NO_3] and [K^+] in leaf sap, leaf area, root and shoot dry weights at 7 WAE, and time from emergence to field transplanting readiness were significantly affected by TBS rates. The extent of TBS effect on shoot height, leaf sap [N-NO_3] and [K^+], time from emergence to field transplanting readiness, leaf area, and root and shoot dry weights at 7 WAE was the same for a given rate when applied at sowing, at emergence, or at 1 WAE. In contrast, none of the variables were significantly affected when TBS was applied 2 WAE, which may be partially attributed to a shorter time for *Trichoderma* activity, as compared to earlier applications.

The following discussion refers to TBS applied at sowing, at emergence, or at 1 WAE. Papaya shoot dry weight increased by approximately 28% above that of control plants as TBS rates increased from 0 to 250 MCS, with little further increase at the rate of 500 MCS (Fig. 1). Similarly, papaya root dry weight increased by nearly 38% when TBS rates increased up to 250 MCS (Fig. 2). Our finding that TBS enhanced papaya shoot and root growth agrees with reports by Ozbay et al. (2004), who found *Trichoderma* significantly increased root and shoot dry weights in tomato, and by Björkman et al. (1998), who found that shoot and root growth increased by 70 and 66%, respectively, in sweet corn treated with *Trichoderma*. Also, Yedidia et al. (2001) reported that *Trichoderma* application in cucumber resulted in root and shoot dry weight

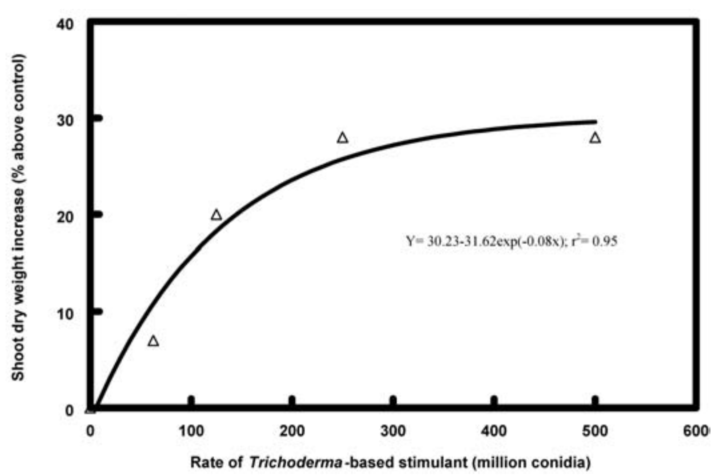

Fig. 1. Papaya transplant shoot dry weight at seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

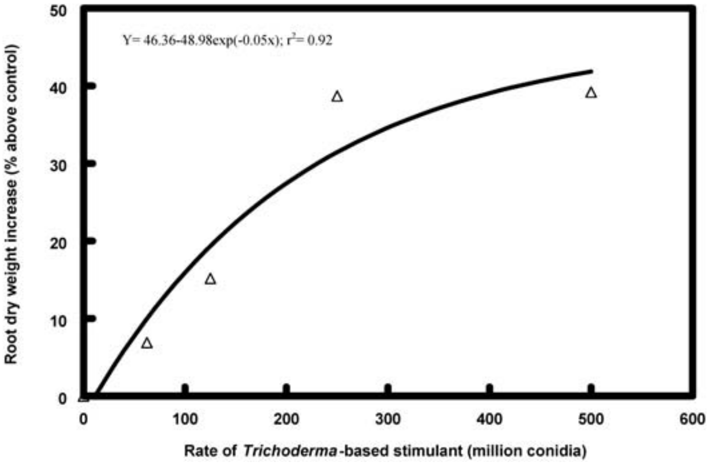

Fig. 2. Papaya transplant root dry weight at seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

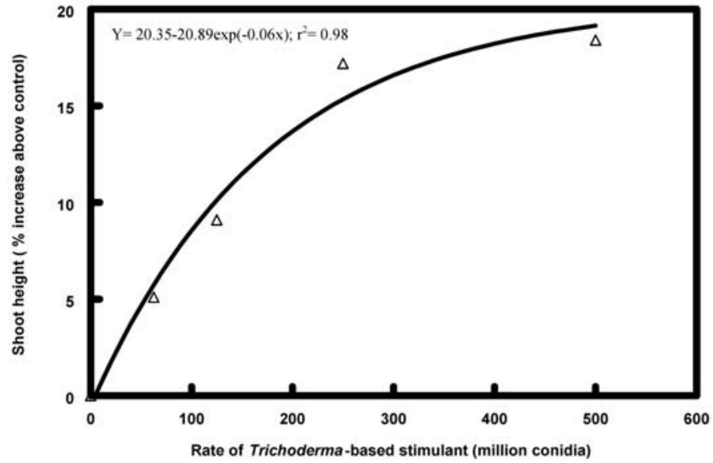

Fig. 4. Papaya transplant shoot height at seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

increases by 40 and 25%, respectively, and root area increase by 95%. Similarly, *Trichoderma* applications in cabbage resulted in 91-102% shoot dry weight increase and 100-158% root dry weight increase (Rabeendran et al., 2000).

When TBS rates were increased from 0 to 250 MCS, papaya leaf area increased by approximately 20%, but increasing the TBS rate to 500 MCS did not further increase leaf area (Fig. 3). Ozbay et al. (2004) reported similar leaf area increases due to *Trichoderma* treatment in tomato seedlings. The effect *Trichoderma* on cabbage and cucumber leaf area was more dramatic, with up to 72 and 80% increase over control plants, respectively (Rabeendran et al., 2000; Yedidia et al., 2001). Papaya seedling shoots were approximately 18% taller in plants treated with TBS at the rates of 250-500 MCS than in control plants (Fig. 4). Ozbay et al. (2004) reported similar height increases in tomato seedlings, but no effects on plant height were found by Morales-Payan (2004) in ornamental pepper (*Capsicum annuum*).

The [N-NO_3] and [K^+] in the leaf sap of papaya seedlings treated with TBS were higher than in control plants. At the TBS rates of 250-500 MCS, [N-NO_3] and [K^+] in petiole sap were between 25 and 28% (Figs. 5 and 6). Our results are in agreement with those of Yedidia et al. (2001), who reported that *Trichoderma* treatments to cucumber resulted in significantly higher concentrations of copper, phosphorus, iron, zinc, sodium, and manganese in the crop shoots, as compared to those of untreated plants. Our results and those of Yedidia et al. (2001) may be explained in part by the findings of Altomare et al. (1999), who reported that *Trichoderma* increased nutrient availability in the soil, which may lead to increased nutrient uptake and accumulation in plants.

Papaya transplants were considered ready for transplanting to the field when the shoot height was >20 cm, the stem was about 1 cm in diameter, and the plant had at least four true leaves (Morales-Payan, 1998; Nishina et al., 2000). Increasing TBS rates resulted in decreasing the time from emergence to transplanting readiness. At the rates of 250 to 500 MCS, time to transplanting readiness was reduced by 10 d (Fig. 7). Thus, at those rates TBS resulted in an approximately 23% reduction in the nursery stage as compared to control plants.

In our experiments, the papaya variables shoot height, leaf sap [N-NO_3] and [K^+], leaf area, and root and shoot dry weights at 7 WAE, and time from emergence to field transplanting readiness responded in the same fashion to TBS rates when applied at sowing, emergence, or 1 WAE. For the

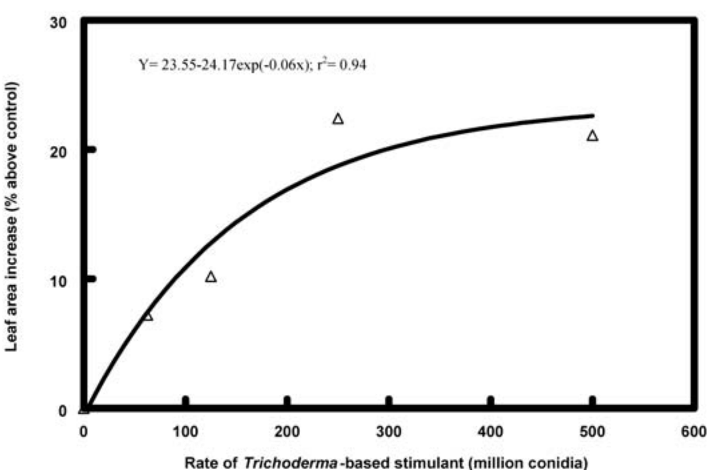

Fig. 3. Papaya transplant leaf area at seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

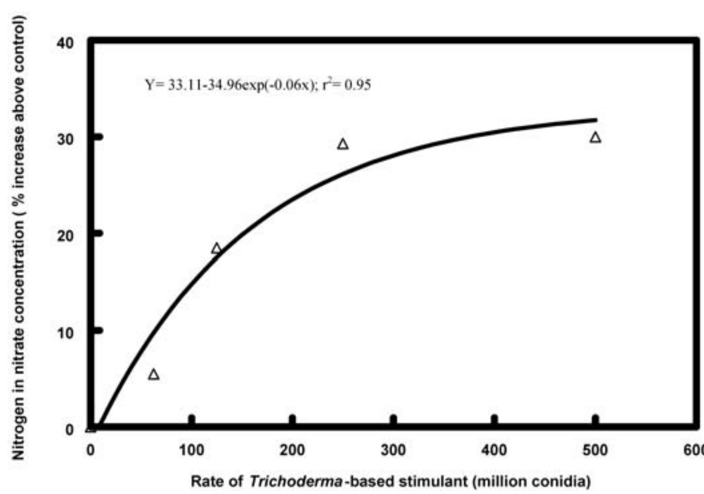

Fig. 5. Papaya transplant nitrogen in nitrate concentration in leaf petiole seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

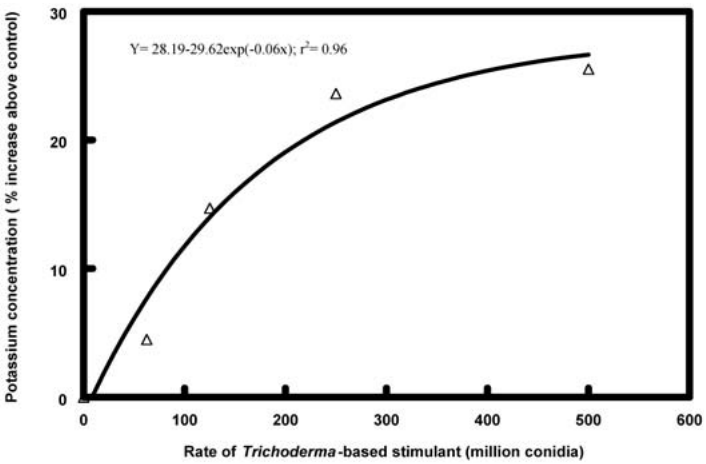

Fig. 6. Papaya transplant potassium concentration in leaf petiole seven weeks after emergence as affected by rates of a *Trichoderma*-based plant stimulant.

aforementioned variables, values increased sharply when TBS rates increased from 0 to 250 MCS, with little or no additional response when the rate increased from 250 to 500 MCS. TBS increased papaya root dry weight more than shoot dry weight. This finding is similar to that of Rabeendran et al. (2000) in cabbage, but disagrees with findings of equal root and shoot dry weight increases in tomato (Ozbay et al., 2004) and sweet corn (Björkman et al., 1998). These results also differ from those of Yedidia et al. (2001), who found a stronger effect of *Trichoderma* on shoot growth than in shoot growth in cucumber. Differences in the magnitude and relative extent of *Trichoderma* effects on shoot and root growth in those crops may be partially attributed to plant species and/or *Trichoderma* species and strains differences. The [N-NO_3] and [K^+] in leaf sap of papaya seedlings treated with TBS was higher than in control plants, which is consistent with the finding that TBS increased root dry weight in our experiments and those of other researchers (Rabeendran et al., 2000; Yedidia et al., 2001). Altomare et al. (1999) found that *Trichoderma* increased nutrient solubility in near plant roots and enhanced uptake and accumulation. Thus, although it was not measured in this research, it is possible that nutrients other than

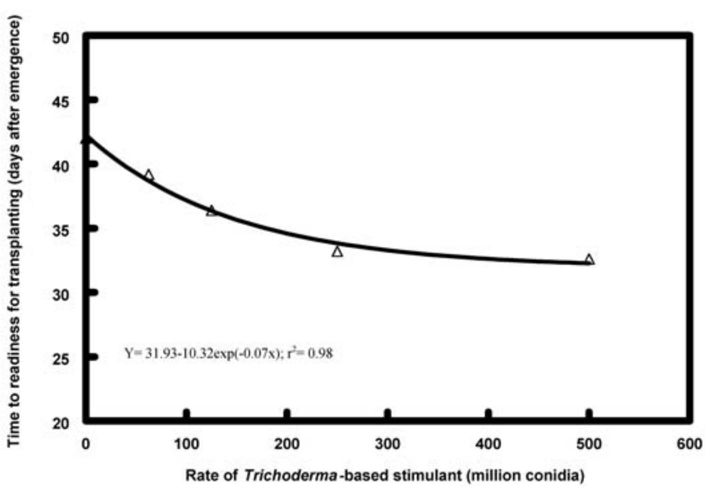

Fig. 7. Time from emergence to readiness for transplanting in papaya transplants as affected by rates of a *Trichoderma*-based plant stimulant.

N and K may have been accumulated in higher concentration in TBS-treated seedlings than in control seedlings. Increased N and K concentration (and maybe other nutrients that we did not measure) in papaya leaf sap may partially explain the overall shoot growth increase found in TBS-treated seedlings, as plants with high N concentration tend to have an accelerated growth rate (Altomare et al., 1999; Björkman et al., 1998, Yedidia et al., 2001).

There was no significant TBS effect on papaya seedling emergence. This finding coincides with those of Kim-Jeong et al. (1992) in petunia (*Petunia hybrida*) and tomato, but is in disagreement with results by Yeridia et al. (2001) and Ozbay et al. (2004), who found that *Trichoderma* significantly enhance germination and emergence in cucumber and tomato, respectively. While the reason for inconsistent *Trichoderma* effects on seedling emergence is not clear, the lack of detectable *Trichoderma* effects on papaya seedling growth when TBS was applied two WAE may be attributed in part to a shorter time of fungal activity, as compared to earlier applications.

Factors such as cultivar, substrates, mineral nutrition, and plant growth regulators have been shown to affect the time necessary to produce adequate papaya transplants (Morales-Payan and Stall, 2003; Nishina et al., 2000; Palmer-Rannie et al., 2002). Our results showed that *Trichoderma* increased N and K accumulation in papaya sap along with overall growth enhancement. Chang et al. (1986) and Windham et al. (1986) suggested that *Trichoderma* secrete root growth stimulating substances and promote nutrient uptake. Altomare et al. (1999) showed that *Trichoderma* increased nutrient availability and root uptake. In our research, the effect of putative growth stimulating substances from *Trichoderma* would be confounded with the effect of *Trichoderma* on nutrient uptake and consequent increase in [N-NO_3] and [K^+] increase in leaf sap.

This research showed that overall papaya seedling growth may be enhanced by *Trichoderma* treatments in the absence of detectable disease, and that the time from seedling emergence to adequate transplanting readiness may be shortened by approximately 20%. Thus, *Trichoderma*-based biostimulants may be a valuable tool in papaya nurseries in general and for organic papaya transplant production in particular.

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