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# Arbuscular mycorrhizal fungi enhance fruit growth and quality of chile ancho (*Capsicum annuum* L. cv San Luis) plants exposed to drought

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**Abstract** The effect of arbuscular mycorrhizal fungi (AMF) and drought on fruit quality was evaluated in chile ancho (*Capsicum annuum* L. cv San Luis). AMF treatments were (1) *Glomus fasciculatum* (AMFG), (2) a fungal species consortium from the forest "Los Tuxtla" in Mexico (AMFT), (3) a fungal species consortium from the Sonorian desert in Mexico (AMFD), and (4) a noninoculated control (NAMF). Plants were exposed to a 26-day drought cycle. Fruit quality was determined by measuring size (length, width, and pedicel length), color, chlorophyll, and carotenoid concentration. Under nondrought conditions, AMFG produced fruits that were 13% wider and 15% longer than the NAMF treatment. Under nondrought conditions, fruit fresh weight was 25% greater in the AMFG treatment compared to the NAMF. Under drought, fruits in the AMFT and AMFD treatments showed fresh weights similar to those in the NAMF treatment not subjected to drought. Fruits of the AMFG treatment subjected to drought showed the same color intensity and chlorophyll content as those of the nondroughted NAMF treatment and carotenoid content increased 1.4 times compared to that in the NAMF not exposed to drought. It is interesting to note that fruits in the AMFD treatment subjected to drought and the NAMF treatment not exposed to drought reached the same size. AMFD treatment increased the concentration of carotenes (1.4 times) under nondrought conditions and the concentration of xanthophylls (1.5 times) under drought when compared to the nondroughted NAMF treatment.

**Keywords** Arbuscular mycorrhizal fungi · Drought · Quality · *Capsicum annuum*

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## Introduction

Fruit quality comprises undesirable attributes (pesticide residues and heavy metals), bioactive substances (glucosinolates, carotenoids, and dietary fibers), essential nutritive compounds (proteins, vitamins, and minerals), and sensory attributes including appearance (shape, size, and color) and texture (Schreiner et al. 2000). Postharvest quality of fresh fruit generally depends on the quality achieved at the time of harvest. Quality is affected by several preharvest factors that include physiological and environmental factors such as nutrition and water. Water availability is an important factor influencing vegetable nutrition and quality. Drought stress limits crop production significantly. This can result in growth and photosynthetic rate reductions or even in plant death (Estrada et al. 1999; Janoudi et al. 1993).

Arbuscular mycorrhizal fungi (AMF) can reduce the negative impact of water stress on plants (Smith and Read 1997; Sánchez-Díaz and Honrubia 1994; Augé 2001). Chile ancho (*Capsicum annuum* L.) is a rich and important source of vitamin C in the Mexican diet. Unfortunately, the most important production area of chile ancho is in the semiarid valleys at the center of Mexico where water availability represents a limiting production factor (Labore and Pozo 1982). Recently, there is a growing interest in the *C. annuum*-AMF symbiosis related to plant phosphorus and water uptake, growth, plant nutritional status, gas

exchange characteristics, and yield (Davies and Linderman 1991; Davies et al. 1993; Aguilera-Gómez et al. 1999; Bagyaraj and Sreeramulu 1982). However, to our knowledge, there is no study related to fruit quality of chile ancho in mycorrhizal plants under drought stress.

The objective of this research was to determine the influence of AMF on quality of chile ancho fruit of droughted and nondroughted plants.

## Materials and methods

### Plant culture

Chile ancho (*C. annuum* L. cv. San Luis) was grown from seeds in a mixture of peat and perlite (1:1, v/v) and 32 seedlings were transplanted after 50 days separately into 2,500 $cm^3$ pots containing 3.2 kg of a mixture methyl bromide sterilized coarse sand and low P sandy loam soil (1:1 v/v). Two hundred grams of soil medium in the center of each pot contained 2,250 spores of one of the three AMF inocula or was nonmycorrhizal. The mycorrhizal treatments were (1) *Glomus fasciculatum* (AMFG); (2) a fungal species consortium from the tropical perinnifolium forest "Los Tuxtla" in Veracruz, Mexico (AMFT) containing *Glomus constrictum*, *Glomus geosporum*, *G. fasciculatum*, and *Glomus tortuosum*; (3) a fungal species consortium from the Sonorian desert in Sonora, Mexico (AMFD) containing *Glomus aggregatum*, *Glomus deserticola*, *G. geosporum*, *Glomus microaggregatum*, and *Sclerocystis coremioides*; and (4) a noninoculated control (NAMF). Plants were irrigated as needed and fertilized weekly with 300 ml per pot of modified Long Ashton solution (Hewitt 1966) to supply 44 mg P $ml^{-1}$ to NAMF plants and 22 mg P $ml^{-1}$ to AMF plants. Previous experiments have shown that 22 mg P $ml^{-1}$ added to AMF inoculated plants resulted in similar plant development as when 44 mg P $ml^{-1}$ was added to nonmycorrhizal plants (Ocampo-Jiménez 2003). Potted plants were maintained in the greenhouse under an average maximum photosynthetic photon flux of 743 μmol $m^{-2}$ $s^{-1}$. Mean day/night temperature 33/13°C and mean relative humidity was 50%. After 70 days in the greenhouse, half of the plants from each treatment were exposed to a 26-day drought cycle that was regulated by monitoring daily evaporative loss and irrigating containers to replenish 90% of the daily water that evaporated. Nondroughted plants were irrigated as needed (soil maintained at 80% of field capacity).

Mycorrhizal colonization was determined on cleared and stained root samples (Phillips and Hayman 1970).

### Plant growth and development

Shoot (leaves + stem), root, and fruit dry weights of four plants were determined after drying at 80°C for 48 h to constant weight. Fruit fresh weight of four plants was also measured.

### Evaluation of fruit quality

Length, width, and pedicel length were recorded. Fruit color was measured on five randomly selected zones of four fruits using a MINOLTA CM-508d colorimeter and were expressed in CIELAB units of $L^*$, $a^*$, $b^*$, and $C^*$. This color scale is based on the opponent-colors theory of color vision and single values can be used to describe the red/green and the yellow/blue attributes. $L^*$ defines lightness, $a^*$ denotes the red/green value, and $b^*$ the yellow/blue value. The center $L^*$ axis shows $L$=100 (white or total reflection) at the top and $L$=0 (black or total absorption) at the bottom. The $a^*$ axis runs from left to right (from −60 to+60). A color measurement movement in the $-a$ direction depicts a shift toward green while $+a$ movement depicts a shift toward red. Along the $b^*$ axis (from −60 to +60), $-b$ movement represents a shift toward blue while $+b$ shows a shift toward yellow. Chroma ($C^*$) indicates the vividness of a color changing in the horizontal plane where colors in the center are dull ($C^*$=0) and become more vivid as they move toward the perimeter ($C^*$>0) (Lancaster et al. 1997; Abbott 1999).

Pigments were extracted using modified methods of the Association of Official Analytical Chemists (AOAC 1984). Three 0.1-g subsamples from four fruits per plant were analyzed for chlorophyll concentration. Frozen tissue was homogenized with 1 ml cold acetone (80%), sonicated for 10 min, and centrifuged at 2,000×$g$ for 2 min. The pellet was homogenized with 1 ml cold acetone (80%), sonicated, and centrifuged. Combined supernatants were adjusted to 3 ml with 80% acetone. Absorbance was measured at 663 and 645 nm in a UV-visible Cary-E3 spectrophotometer. Chlorophyll concentration was calculated using the equation:

$$\text{Chlorophyll}\left(\text{mg g}^{-1}\right) = 20.2 \times A_{645} + 8.05 \times A_{663}$$

Concentration of carotenoids was determined from three 0.1 g subsamples from four fruits per plant. Frozen tissue was homogenized with 10 ml of cold HEAT solution (hexane-ethanol-acetone-toluene 10:6:7:7 v/v), transferred to a 50 ml Erlenmeyer flask with 30 ml HEAT solution, and sonicated for 10 min. Two drops of water and 2 ml of methanolic potassium hydroxide solution (KOH 40%) were added and mixed for 1 min. The flask was protected from light and shaken for 16 h at 20°C. The extracts were adjusted with 30 ml of hexane, shaken for 1 min, and kept for 1 h. An aliquot was taken from the epiphase and absorbance was measured at 436 and 474 nm in a UV-visible Cary-E3 spectrophotometer. Carotenoid concentration was calculated using the equations:

$$\text{Carotenes (mg)} = \left(A_{436} \times V\right)/196 \times b\right) \quad \text{and}$$
$$\text{Xanthophylls (mg)} = \left(A_{474} \times V\right)/(236 \times b)$$

where $V$ is the volume of dilution, $b$ is the length of cell (1 cm). The values 196 and 236 are coefficients of specific absorption.

### Experimental design and statistical analysis

The four AMF ×2 drought level factorial experiment was in a completely randomized design with each plant as a single replicate. There were four plants per treatment. Measurements of growth and development parameters (shoot, root and fruit dry weights, and fruit fresh weight) were made on four plants per treatment ($n$=4). Fruit quality measurements were made on fruits of four plants ($n$=4). Mycorrhizal colonization was determined on roots of four plants. There were 15 slides containing ten root segments (1 cm) and three microscopic observations were made at the top, middle, and bottom ($n$=450 observations per treatment).

Statistical significance of the data was determined using analysis of variance (ANOVA). Mean separation was tested by minimum significant difference at $P$<0.05 (FAUANL 1994).

## Results

Mycorrhizal colonization was successful in all our AMF treatments. However, the highest colonization in terms of arbuscules was achieved by the AMFD treatment (Table 1).

The impact of mycorrhizal fungi on dry weights of shoots, roots, and fruits; on total dry biomass; and on fruit fresh weight was analyzed. Dry weights of shoot were significantly higher ($P$<0.05) in the AMF treatments than in the NAMF treatment under drought and nondrought conditions (Table 2).

Under nondrought conditions, shoot dry weight increased, particularly in plants of the AMFT (72%), compared to those in the NAMF treatment, while under drought conditions, plants in the AMFD treatment had the greatest shoot dry weights (39% larger than those in the NAMF treatment not exposed to drought) (Table 2).

AMF treatment had no significant effect on root dry weight under nondrought conditions. In contrast, AMF inoculation led to decreasing root dry weight in the case of AMFG and AMFT treatments (46 and 47%, respectively) compared to the NAMF treatment. Dry weight of fruit also showed significant differences among AMF treatments (Table 2). Under nondrought conditions, the fruit dry weights in the AMFG and AMFD treatments showed an increase of 107 and 80%, respectively, compared with those in the NAMF treatment. It is interesting to note that under drought conditions, all treatments had significantly greater fruit dry weights compared to the NAMF treatment not subjected to drought. The best response was obtained with the AMFD (98% higher than that in the NAMF treatment not subjected to drought).

The total dry biomass in all AMF treatments was larger than in the NAMF treatment under nondrought conditions. Under drought conditions, plants in the AMFD treatment showed dry biomass 48% larger than that in the NAMF treatment under nondrought conditions.

AM colonization improved fruit fresh weight in nondroughted plants. The highest increase was obtained in the AMFG treatment (25% larger than that in the NAMF treatment). Under drought conditions, fruit fresh weight decreased in the AMFG treatment (20% less than that in the NAMF treatment not subjected to drought), while it increased in the AMFD treatment (8% larger than that in the NAMF treatment not subjected to drought) (Table 2).

Regarding the fruit quality as evaluated by size, color (lightness $L$*, components $a$* and $b$*, and chroma $C$*), and pigment concentration, there were significant differences among AMF treatments. Under nondrought conditions, the highest fruit width was observed in the AMFG treatment (13% higher than that in the NAMF treatment). Under drought stress, no significant differences were found on fruit width in the AMFT and AMFD treatments (Table 3). Concerning the fruit length, the AMFG and AMFT treatments exhibited an increase of 15 and 12%, respectively, compared to those in the NAMF treatment under nondrought conditions. Under drought, the best response was obtained in the AMFG treatment where the fruits were 11% longer than those in the NAMF treatment not exposed to drought. Significant differences in pedicel length were found under drought stress. In this case, only the AMFD treatment did not show a decrease in pedicel length (5% higher than that in the nondroughted NAMF treatment) (Table 3).

**Table 1** Root colonization of chile ancho (*C. annuum* L. cv San Luis) under drought and nondrought conditions

| AMF | Drought | Root colonization (%) | Vesicles (%) | Arbuscules (%) |
|---|---|---|---|---|
| NAMF | No | 0 | 0 | 0 |
| AMFG | | 93 a | 51 c | 50 b |
| AMFT | | 95 a | 47 c | 46 b |
| AMFD | | 91 a | 62 bc | 64 ab |
| NAMF | Yes | 0 | 0 | 0 |
| AMFG | | 83 a | 67 ab | 38 bc |
| AMFT | | 85 a | 72 ab | 32 c |
| AMFD | | 97 a | 78 a | 78 a |

Means followed by different letters within each column are significantly different based on DMS test ($P$<0.05, $n$=450)
*NAMF* Noninoculated control; *AMFG G. fasciculatum*; *AMFT* fungal species consortium from a tropical perinnifolium forest containing *G. constrictum*, *G. geosporum*, *G. fasciculatum*, and *G. tortuosum*; and *AMFD* fungal species consortium from desert containing *G. aggregatum*, *G. deserticola*, *G. geosporum*, *G. microaggregatum*, and *S. coremioides*

**Table 2** Effect of arbuscular mycorrhizal fungi (AMF) and drought stress on plant growth and development measurements of chile ancho (*C. annuum* L. cv San Luis)

| AMF | Drought | Shoot dry weight (g) | Root dry weight (g) | Fruit dry weight (g) | Total dry biomass (g) | Fruit fresh weight (g) |
|---|---|---|---|---|---|---|
| NAMF | No | 5.7±1.5 d | 4.5±1.2 a | 5.6±1.7 c | 15.8 | 40.8±2.7 c |
| AMFG | | 7.8±0.9 bc | 4.6±0.5 a | 11.6±2.1 a | 23.9 | 50.8±3.0 a |
| AMFT | | 9.8±1.7 a | 4.7±1.2 a | 5.4±1.9 bcd | 22.9 | 41.5±1.9 c |
| AMFD | | 9.2±1.2 ab | 4.2±0.5 a | 10.1±3.2 abc | 23.5 | 47.1±1.7 ab |
| NAMF | Yes | 5.6±0.5 d | 4.1±0.7 a | 7.8±1.0 cd | 17.5 | 21.7±1.8 e |
| AMFG | | 7.2±1.2 bcd | 2.9±0.8 b | 9.8±1.1 abc | 19.9 | 32.8±3.6 d |
| AMFT | | 7.1±0.9 cd | 2.4±1.1 b | 9.2±2.1 abc | 18.6 | 41.3±1.6 c |
| AMFD | | 7.9±0.2 abc | 4.4±1.4 a | 11.1±1.1 ab | 23.4 | 43.9±3.3 bc |

Mean and standard error are presented. Different letters within each column indicate significant differences based on DMS test ($P<0.05$, $n=4$)
*NAMF* Noninoculated control; *AMFG G. fasciculatum*; *AMFT* fungal species consortium from a tropical perinnifolium forest containing *G. constrictum*, *G. geosporum*, *G. fasciculatum*, and *G. tortuosum*; and *AMFD* fungal species consortium from desert containing *G. aggregatum*, *G. deserticola*, *G. geosporum*, *G. microaggregatum*, and *S. coremioides*

The best lightness ($L^*$, i.e., lowest) was obtained with AMFD treatment, which had a lightness of about 17 in both drought and nondrought conditions (Table 4). There was no positive effect of AMF treatments on $a^*$ and the $a^*$ values of all treatments were lower than those of the NAMF treatment (−7.0). There was no significant difference between the best AMF treatment (AMFG with $a^*$ value of −6.6) under drought conditions and the NAMF treatment (with $a^*$ value of −7.0) under nondrought conditions (Table 4). Fruit in all AMF treatments did not show a significant increase in $b^*$ compared to the NAMF treatment. However, under drought stress, the AMFG treatment resulted in the highest $b^*$ value (9.6) compared to the NAMF treatment under nondrought conditions (Table 4). AMF did not increase $C^*$ significantly compared to the NAMF treatment under nondrought conditions ($C^*$=10.9). Under drought stress, the AMFG treatment reached the $C^*$ value of the NAMF treatment not subjected to drought (Table 4).

Chile ancho fruit color is due to the presence of the pigments, chlorophyll, and carotenoids (carotenes and xanthophylls) within the fruit. The concentration of pigments in the fruit was significantly affected by the AMF inoculation (Table 5). Under nondrought conditions, the AMF treatments influenced the chlorophyll concentration, particularly the AMFT treatment in which the chlorophyll concentration was about 1.5 times lower than that in fruits of the NAMF treatment. Under drought, the chlorophyll content in the AMFG treatment reached similar concentration to the NAMF treatment not subjected to drought. The highest carotene content was obtained with the AMFD treatment under nondrought stress where the carotene content was 1.4 times higher than that of the nondroughted NAMF plants. Under drought stress, the treatments that responded positively were AMFG and AMFT with an increase of 1.4 and 1.3 times, respectively, compared to the NAMF treatment not subjected to drought. The highest xanthophyll concentration was obtained in the AMFD treatment with an increase of 1.5 times compared to the NAMF treatment not subjected to drought. Under drought stress, the treatments AMFG and AMFT increased xanthophyll content 1.4 times compared to the NAMF treatment not subjected to drought.

**Table 3** Effect of arbuscular mycorrhizal fungi (AMF) and drought stress on size of chile ancho fruit (*C. annuum* L. cv San Luis)

| AMF | Drought | Width (cm) | Length (cm) | Pedicel length (cm) |
|---|---|---|---|---|
| NAMF | No | 4.8±0.2 c | 8.1±0.6 c | 4.4±0.3 ab |
| AMFG | | 5.4±0.6 a | 9.3±1.0 a | 4.2±0.2 bc |
| AMFT | | 4.7±0.2 cd | 9.1±0.1 ab | 4.4±0.3 ab |
| AMFD | | 5.3±0.1 ab | 8.1±0.7 c | 4.3±0.1 c |
| NAMF | Yes | 3.9±0.3 e | 7.0±0.3 d | 3.2±0.2 d |
| AMFG | | 4.3±0.2 de | 9.0±0.2 ab | 4.0±0.1 c |
| AMFT | | 4.9±0.2 bc | 8.4±0.2 bc | 4.2±0.1 bc |
| AMFD | | 5.0±0.1 abc | 7.8±0.1 c | 4.6±0.4 a |

Mean and standard error are presented. Different letters within each column indicate significant differences based on DMS test (P<0.05, $n=4$)
*NAMF* Noninoculated control; *AMFG G. fasciculatum*; *AMFT* fungal species consortium from a tropical perinnifolium forest containing *G. constrictum*, *G. geosporum*, *G. fasciculatum*, and *G. tortuosum*; and *AMFD* fungal species consortium from desert containing *G. aggregatum*, *G. deserticola*, *G. geosporum*, *G. microaggregatum*, and *S. coremioides*

**Table 4** Effect of arbuscular mycorrhizal fungi (AMF) and drought stress on color of chile ancho fruit (*C. annuum* L. cv San Luis)

| AMF | Drought | *L** | *a** | *b** | *C** |
|---|---|---|---|---|---|
| NAMF | No | 20.4±0.7 ab | −7.0±0.5 a | 8.3±0.9 b | 10.9±0.9 ab |
| AMFG | | 19.3±1.7 bc | −5.4±0.4 e | 6.9±0.2 de | 8.7±0.4 e |
| AMFT | | 23.4±1.6 a | −6.3±0.4 bc | 8.4±0.3 b | 10.5±0.4 bc |
| AMFD | | 17.8±1.3 bc | −6.0±0.4 cd | 7.7±0.7 bc | 9.7±0.7 cd |
| NAMF | Yes | 18.8±1.5 bc | −6.1±0.5 bcd | 6.7±0.4 ef | 9.2±0.2 de |
| AMFG | | 20.9±1.7 ab | −6.6±0.2 ab | 9.6±0.6 a | 11.6±0.7 a |
| AMFT | | 18.3±0.5 bc | −5.6±0.3 de | 7.5±0.2 cd | 9.3±0.4 de |
| AMFD | | 17.0±1.0 c | −4.4±0.2 f | 6.0±0.3 f | 7.5±0.3 f |

Mean and standard error are presented. Different letters within each column indicate significant differences based on DMS test ($P<0.05$, $n=4$)

*NAMF* Noninoculated control; *AMFG G. fasciculatum*; *AMFT* fungal species consortium from a tropical perinnifolium forest containing *G. constrictum*, *G. geosporum*, *G. fasciculatum*, and *G. tortuosum*; and *AMFD* fungal species consortium from desert containing *G. aggregatum*, *G. deserticola*, *G. geosporum*, *G. microaggregatum*, and *S. coremioides*

*L** indicates lightness from white =100 to black =0; *a** and *b** are *XY* color coordinates where *a** is the red-green axis (from −60 to +60), *b** is the yellow-blue axis (from −60 to +60), and *C** relates both *a** and *b** [$C^*=(a^{*2}+b^{*2})^{1/2}$] indicating the vividness of the color

## Discussion

The positive effects of AMF inoculation were clearly demonstrated on growth, development, and fruit quality of chile ancho under drought stress.

The AMF enhanced shoot and fruit dry weights and the total dry biomass. Similar results were obtained previously (Aguilera-Gómez et al. 1999). Chile ancho plants response depended on the AMF inocula applied as consortium or as single strain, and the water conditions.

Dry matter of NAMF plants (shoot, root, fruit, and total biomass) was not reduced under drought as reported by Davies et al. (2002). This could be explained by the level of stress applied in our experimental conditions. Leaf water potential measurements revealed a moderate water stress compared to that applied by Davies et al. (2002) (data not shown). These authors also reported enhanced plant resistance to drought using an AMF consortium. The clearest effect of drought was observed on fruit fresh weight, which was significantly reduced in plants of the NAMF treatment, as was previously reported in many other crops such as olive (Inglese et al. 1996) and muskmelon (Lester et al. 1994). The AMF consortia mitigated the detrimental impact of water stress on fruit fresh weight.

Despite the influence of AMF on crop yield as documented in many reports (Bagyaraj and Sreeramulu 1982; Duffy and Cassells 2000), little is known about the potential of AMF for improving fruit quality. We clearly demonstrated the positive impact of AMF on fruit quality of chile ancho in terms of size, color, and pigment content.

The fruit size as determined by width, length, and pedicel length, responded to mycorrhizal inoculation and the extent of the response varied with the AMF. The AMFG treatment produced the largest fruits under nondrought conditions. Water and nutrient flow through the leaves could be limited under drought, thereby influencing the size of the fruit. However, inoculation of plant roots with consortium AMFD improved fruit size under drought conditions. This could be related to the pattern of dry matter distribution in inoculated plants, which pointed to a role of AMF in carbon partition. The impact of AMF on fruit quality was investigated previously under nondrought conditions (Charron et al. 2001). The authors reported a larger final bulb diameter in AMF plants

**Table 5** Effect of arbuscular mycorrhizal fungi (AMF) and drought stress on chlorophyll and carotenoids concentration of chile ancho fresh fruit (*C. annuum* L. cv San Luis)

| AMF | Drought | Chlorophyll (μg $g^{-1}$) | Carotenes (μg $g^{-1}$) | Xanthophylls (μg $g^{-1}$) |
|---|---|---|---|---|
| NAMF | No | 141±10.0 a | 8.8±0.7 c | 7.0±0.2 cd |
| AMFG | | 105±10.0 bc | 8.8±0.2 c | 7.4±0.1 c |
| AMFT | | 96±3.0 c | 8.3±0.3 cd | 7.3±0.2 c |
| AMFD | | 107±6.0 bc | 12.5±0.5 a | 10.6±0.7 a |
| NAMF | Yes | 64±7.0 d | 8.0±0.5 d | 6.6±0.4 d |
| AMFG | | 147±14.0 a | 12.3±0.2 a | 10.0±0.3 b |
| AMFT | | 116±17.0 b | 11.5±1.0 b | 9.5±0.7 b |
| AMFD | | 104±17.0 bc | 8.6±0.1 cd | 7.4±0.1 c |

Mean and standard error are presented. Different letters within each column indicate significant differences based on DMS test ($P<0.05$, $n=4$)

*NAMF* Noninoculated control; *AMFG G. fasciculatum*; *AMFT* fungal species consortium from a tropical perinnifolium forest containing *G. constrictum*, *G. geosporum*, *G. fasciculatum*, and *G. tortuosum*; and *AMFD* fungal species consortium from desert containing *G. aggregatum*, *G. deserticola*, *G. geosporum*, *G. microaggregatum*, and *S. coremioides*

compared to those from noninoculated plants. In addition, they found that onion bulbs (*Allium cepa*) in plants inoculated with *Glomus versiforme* were firmer than those in plants inoculated with *Glomus intraradices*.

Not only fruit size, but also fruit color is essential for making purchasing decisions. For instance, AMF inoculation influenced all color components measured in fruits used in this study ($L^*$, $a^*$, $b^*$, and $C^*$). This is the first time that the effect of AMF on the fruit color component was reported. Changes in color were also dependent on drought treatments. The AMFG treatment promoted the most adequate color development of fruits under drought conditions, while the other AMF treatments did not achieve an acceptable color due to water stress.

In *C. annuum* fruits, color depends mainly on the chlorophyll and carotenoid composition. The content of chlorophyll in fruits of the nondroughted NAMF treatment reached a value (141 $\mu g\ g^{-1}$) intermediate between those found in *Bola* (98 $\mu g\ g^{-1}$) and *Agridulce* (172 $\mu g\ g^{-1}$) varieties by Mínguez-Mosquera and Hornero-Méndez (1994). The content of carotenoids (15 $\mu g\ g^{-1}$) was lower than that found in those varieties (35 $\mu g\ g^{-1}$ and 39 $\mu g\ g^{-1}$, respectively). This could depend on the pepper cultivar.

Inoculation with AMF promoted a reduction of chlorophyll concentration in fruits of well-watered plants. Only the treatment AMFD promoted a significant accumulation of carotenoids in fruits. We observed the highest concentration of all pigments in fruits having the most intense color (the highest $C^*$ values). Fruits from drought-stressed plants in the AMFG treatment produced these intense colors.

Fruit pigment concentration is directly related to fruit ripening. Chlorophyll content decreases with ripening, while concentration of carotenoids increases (Brady 1987; Govindarajan et al. 1987). Changes found in the distribution pattern of pigments in this study could be an effect of the AMF treatments on the ripening process, altering chlorophyll degradation, and carotenoid accumulation. However, more research must be performed in this area. The increase of pigment concentration in fruits of inoculated plants subjected to drought could be related to the changes in photosynthetic pigment concentration reported previously in leaves due to AMF colonization (Demir 2004) or drought (Alamillo and Bartels 2001).

Other chemical compounds that determine the quality of *C. annuum* fruit are capsaicinoids, a group of pungent phenolics derived from the phenylpropanoid pathway. Although the accumulation of capsaicinoids due to water stress was reported by Estrada et al. (1999), in our study, drought did not influence the production of these secondary metabolites (data not shown). Moreover, we found no effect of AMF inoculation on capsaicinoids concentration.

In summary, this study shows that AMF inoculation can mitigate the adverse effect of drought, restoring key fruit quality parameters to levels similar to those in nondroughted plants. Although the positive effects on AMF in plants were attributed to changes in water relations resulting from enhanced P nutrition (Bethlenfalvay et al. 1988; Ruiz-Lozano et al. 1995; Kaya et al. 2003), the involvement of P remains controversial. Many reports suggested that AMF colonization improved drought resistance independently of P status (Davies et al. 1993, 2002). We found a positive effect of AMF at low levels of P fertilization. However, the P content was not evaluated in this experiment.

The positive impact of AMF could also be explained by differences in colonization levels. The high percentage of arbuscules in the AMFD treatment indicated a very active symbiosis especially under drought conditions (Smith and Read 1997), even though it is not clear how a greater formation of arbuscules could contribute to increased plant drought resistance.

It would be very useful to determine effective host plant root-AMF combinations for practical use in the field because the present study supports the utilization of AMF for improving fruit quality, reducing the use of water supply, and phosphorus fertilization, hence making its production more profitable and environment-friendly.

Much work remains to be done to determine the physiological basis for the effects of AMF on fruit.

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