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Sweet Pepper (*Capsicum annuum* L.) Performances as Subjected to Arbuscular Mycorrhizal Fungi and Different Molybdenum Doses

Leo Sabatino[1], Giuseppe Virga[2], Davide Farruggia[1], Nicolò Iacuzzi[1], Beppe Benedetto Consentino[1]
[1] Dipartimento di Scienze Agrarie, Alimentari e Forestali, Università degli Studi di Palermo.
Autore corrispondente: Leo Sabatino
[2] Consorzio di Ricerca per lo Sviluppo di Sistemi Innovativi Agroambientali

Introduction

Sweet pepper (*Capsicum annuum* L.) is one of the most appreciated fruiting vegetables grown all over the world (Faostat, 2020). Arbuscular mycorrhiza (AM) fungi are obligate symbionts between higher plants and fungi belonging to the monophyletic phylum *Glomeromycota* (Schüßle et al., 2001). As reported by Rouphael et al. (2015), it is well known that AM symbiosis improves macro- and micro-nutrients uptake and efficiency due to its capacity to develop an external hypha up to 40-50 times their length. Furthermore, recent outcomes demonstrated that AM fungi enhance yield and quality of vegetables (Sabatino et al., 2020), under favourable or unfavourable cultivation conditions, via a modulation of the plant secondary metabolism (Zhu et al., 2011; Kumar et al., 2015). Molybdenum (Mo) is a trace element indispensable to overcome several human disorders connected to the simple deficiency of sulphite oxidase (Cohen et al., 1971). Simultaneously, it is well documented that plants benefits from Mo-enrichment (Marschner, 2012; Sabatino et al., 2021). Taking into consideration the aforesaid premise, the aim of the present study was to appraise the impact of the AM fungi and Mo biofortification on yield and yield-related traits, nutritional and functional features of a sweet pepper F1 hybrid grown in a protected environment.

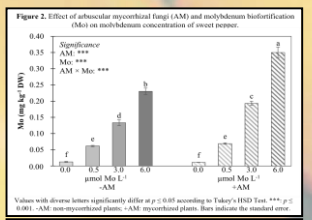

Figure 2. Effect of arbuscular mycorrhizal fungi (AM) and molybdenum biofortification (Mo) on molybdenum concentration of sweet pepper.

Materials and Methods

The trial was carried out in Marsala, Trapani province (Italy), at an experimental field of the Department of Agricultural, Food and Forestry Sciences of the University of Palermo. Prior to transplanting, half of the plants were inoculated with 10 g plant^{-1} of micorrhizal inoculum carrying 40 spores g^{-1} of *Glomus intraradices*. All 'Golden Italian SS' F_1 (Seno Seed srls, Rovigo, Italy) sweet pepper plants were transplanted on 10 February, 2020 and maintained till the end of May, 2020 in a tunnel. Mulching with a black polyethylene film of 20 µm was installed. Sweet pepper plants were spaced to obtain a plant density of 2 plants m^{-2}. Plants were fertigated as recommended by Maroto et al. (2002). Mo was supplied fortnight via foliar spray in form of sodium molybdate (Na_2MoO_4) starting ten days after transplant. The AM treatments (-AM and +AM) were combined with four Mo doses (0, 0.5, 3 or 6 µmol L^{-1}). All treatments were replicated 3 times (10 plants each one) and arranged in a randomized complete block design, rendering 24 experimental units. After harvest, the fruits were weighed and separated into marketable, unmarketable yield and sunscald-affected yield categories. All nutritional and functional traits were determined using the official methods (Singleton and Rossi,1965; Sabatino et al., 2020; Sabatino et al., 2019). All the data were analyzed by two-way ANOVA. The significance level $p \leq 0.05$ was used, and the significant differences among means were evaluated using tuckey's HSD test. A Heat map including all traits was also performed using the online program package (https://biit.cs.ut.ee/clustvis/) (Figure 1).

Results

The +AM × 3.0 µmol Mo L^{-1} combination significantly increased mycorrhizal colonization (MC), total yield (TY), marketable yield (MY) and marketable fruit number (MFN) compared with the untreated control (-AM × 0.0 µmol Mo L^{-1}) (Table 1). However, irrespective of the AM treatment, Mo application with a dosage of 0.5 or 3.0 µmol L^{-1} significantly enhanced mean marketable fruit weight (MMFW) (Table 2). The -AM × 6.0 µmol Mo L^{-1} combination significantly improved SSC and total phenolics (TP) (Table 1). Regardless of the Mo supply, -AM plants had a higher sunscald-affected yield compared with those inoculated (+AM) (Table 2). Whereas, without regard of the AM treatment, the highest sunscald-affected yield was recorded in fruits from plants supplied with 6.0 µmol Mo L^{-1}. The lowest value was observed in the fruits from plants exposed to 3.0 µmol Mo L^{-1}. Irrespective of the Mo application, AM fungi enhanced ascorbic acid (AA) concentration (Table 2). Regardless of the AM treatment, AA fruit concentration increased as Mo concentration in the nutrient solution increased. ANOVA analysis for Mo fruit concentration revealed a significant effect of the interaction AM × Mo (Table 1); the highest Mo fruit concentration was found in fruits from AM inoculated plants and supplied with the highest Mo dosage, followed by those exposed to -AM × 6 µmol Mo L^{-1} combination treatments (Figure 2). The lowest Mo concentration was observed in fruits from -AM or +AM plants combined with 0.0 µmol Mo L^{-1} (Figure 2).

Table 1. Effects of arbuscular mycorrhizal fungi (AM) and molybdenum biofortification (Mo) on mycorrhizal colonization (MC), total yield (TY), marketable yield (MY), marketable fruits number (MFN), soluble solid content (SSC), total phenolics (TP) and fruit molybdenum concentration of sweet pepper.

Treatments	MC (%)	TY (kg plant^{-1})	MY (kg plant^{-1})	MFN (No plant^{-1})	SSC (°Brix)	TP (mg CAE kg^{-1} FW)
-AM × 0.0 µmol Mo L-1	1.7 c	3.4 c	3.1 c	14.6 b	6.0 e	194.0 e
-AM × 0.5 µmol Mo L-1	1.3 c	4.3 b	4.1 b	17.3 ab	6.3 d	208.3 d
-AM × 3.0 µmol Mo L-1	2.0 c	3.3 c	3.2 c	12.7 c	7.1 b	239.7 b
-AM × 6.0 µmol Mo L-1	2.0 c	2.8 d	2.5 d	12.9 c	7.6 a	259.2 a
+AM × 0.0 µmol Mo L-1	85.0 a	4.1 bc	3.8 bc	18.3 a	6.6 c	185.9 f
+AM × 0.5 µmol Mo L-1	85.0 a	4.4 b	4.2 b	17.7 ab	7.1 b	195.1 e
+AM × 3.0 µmol Mo L-1	70.7 b	5.2 a	4.9 a	19.7 a	7.3 b	213.4 d
+AM × 6.0 µmol Mo L-1	60.0 b	3.4 c	3.0 cd	15.2 b	7.8 a	232.1 c
Significance						
AM	***	***	***	***	***	***
Mo	*	***	***	***	***	***
AM × Mo	**	***	***	**	**	***

Values within a column followed by diverse letters significantly differ at $p \leq 0.05$ according to Tukey's HSD Test. *, **, *** significant at $p \leq 0.05$, 0.01 or 0.001, respectively. -AM: non-mycorrhized plants; +AM: mycorrhized plants.

Table 2. Effect of arbuscular mycorrhizal fungi (AM) and molybdenum biofortification (Mo) on mean marketable fruit weight (MMFW), sunscald-affected yield (SAY), fruit dry matter (FDM) and ascorbic acid (AA) of sweet pepper.

Treatments	MMFW (g fruit^{-1})	SAY (g plant^{-1})	FDM (%)	AA (mg 100 g^{-1} FW)
AM				
-AM	224.8 a	188.1 a	4.0 a	78.8 b
+AM	223.4 a	98.1 b	4.7 a	85.2 a
µmol Mo L-1 (Mo)				
0.0	212.0 b	176.4 ab	4.5 a	74.6 d
0.5	238.7 a	104.0 bc	5.4 a	79.2 c
3.0	251.3 a	77.5 c	4.5 a	85.8 b
6.0	194.3 b	208.7 a	3.2 b	88.5 a
Significance				
AM	NS	***	NS	***
Mo	***	***	**	***
AM × Mo	NS	NS	NS	NS

Values within a column followed by diverse letters significantly differ at $p \leq 0.05$ according to Tukey's HSD Test. NS, **, *** non-significant, significant at $p \leq 0.01$ or 0.001, respectively. -AM: non-mycorrhized plants; +AM: mycorrhized plants.

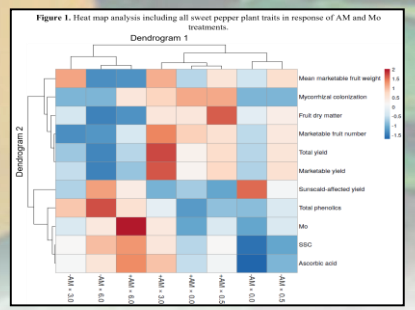

Figure 1. Heat map analysis including all sweet pepper plant traits in response of AM and Mo treatments.

Conclusions

In the present study, AM fungi and Mo biofortification significantly interacted, enhancing crop performance and quality of 'Golden Italian SS' sweet pepper. Nevertheless, the AM treatment combined with 0.5 or 3.0 µmol Mo L^{-1} stood out as generating the best results in terms of the yield and quality traits. We may also hypothesize that AM fungi had a buffer effect on plant Mo toxicity.

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