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EFFECT OF PARTICLE SIZE AND REUSED ORGANIC SUBSTRATES ON TOMATO CROP PRODUCTION

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□ *The bagasse of mezcal maguey and the fiber of coconut fruit are organic byproducts of the mezcal and copra agro-industries in Oaxaca, Mexico. The effects of different particle sizes and prior usage times as substrates on the production and quality of tomato (*Lycopersicon esculentum *Mill) were studied. Three independent and simultaneous experiments were conducted in multi-tunnel greenhouses. Three prior growing cycles of tomato crop, each 150 days in length days of use (DOU), were used for the usage time experiments with mezcal maguey bagasse as the growth medium. In the first experiment, tomato plants grown on substrate with 150 DOU produced the highest yields, the largest number of commercial quality fruits and the fewest non-commercial quality fruits. In the second experiment, the combination of fine particle size and maguey bagasse substrate with 150 DOU produced the highest yields. In the third experiment, fine and medium-sized particles of maguey bagasse and coconut fiber produced the highest yields. The data indicate that both coconut fiber and mezcal maguey bagasse can be used as substrates for tomato cultivation without affecting fruit quality; furthermore, the use of fine and medium-sized particles increases production. Maguey bagasse with up to 150 DOU as a substrate is best for culture, as prior usage beyond this length of time negatively affects production.*

Keywords: soilless crop, reused substrate, maguey bagasse residue

INTRODUCTION

The cultivation of mezcal maguey (*Agave* spp) is of economic and environmental importance in southern Mexico because numerous products, including drinks, rope, food, fodder, timber, and medicinal products, are

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derived from its stem, known as "piña", and its leaves (Silva et al., 2003). Mezcal maguey also is considered a pioneer species on marginal lands with steep slopes. When the stem is processed by the traditional methods of cooking, grinding and distillation, the main product is an alcoholic beverage regionally known as mezcal, which represents 80–86% of the total weight of the "piña", depending on the type of grinding used. The remaining 14–20% is the maguey bagasse byproduct (Silva et al., 2003). In an area of Oaxaca known as "del Mezcal", located in the Valles Centrales and Sierra Sur regions of the state and covering 59 municipalities and 152 communities, mezcal maguey is grown on approximately 11,756 ha (Arredondo et al., 2003). In 1999, an estimated 11,329,553 *Agave* spp plants were used as the raw material for the production of 3,433,768 L of mezcal, with 4,807,275 tons of bagasse byproduct. The byproduct poses serious environmental problems because it is typically poured into rivers and streams and used minimally as fuel in brick kilns. Also in Oaxaca, the soilless culture of vegetables in greenhouses, including tomato (*Lycopersicon esculentum* Mill.), has increased sharply over the past ten years (OEIDRUS, 2008), with a clear tendency for continued increase (Martínez-Gutiérrez et al., 2012). In these production systems, crops may be grown on soil (OjodeAgua et al., 2008; Garcia et al., 2001) or without soil. In the latter case, the inorganic materials most commonly used as substrates are sand, red and black volcanic rock (OjodeAgua et al., 2008), rock wool, and perlite. Of these, rock wool and perlite are expensive and cause contamination when not properly disposed. On the other hand, the organic material most commonly used for ornamental and seed plants is Sphagnum peat, whereas forest soil and different types of compost are used for vegetables (Lopez et al., 2005). Coconut powder used for vegetables and has physical, chemical and biological characteristics suitable for a culture medium (García et al., 2001). In this regard, there are many ways in which mezcal maguey bagasse may compete with traditional organic materials because of its particular morphological characteristics, including hard fibers (Idarraga, 1999) and low density, and its permanent annual availability and abundance. When Martínez-Gutiérrez et al. (2012) evaluated coconut powder and vermiculite substrates, unmixed or in mixtures, and mezcal maguey bagasse, the values for bagasse byproduct from the mezcal industry for all physical, chemical and biological parameters were at the reference levels described by Abad et al. (2004), with the exception of pH, which would need to be reduced for use. A mixture of 25% coconut and 75% vermiculite was usable as a substrate for growing tomatoes, and a mixture of 25% mezcal maguey bagasse and 75% vermiculite was suitable for growing melons. It remains necessary, however, to assess essential parameters for the renewal of organic and inorganic materials as substrates within soilless production systems. These parameters include optimum particle size and prior usage time as a substrate within a container. Furthermore, to reduce the cost of substrates, farmers need to reuse for several crop cycles substrates. In this regard, Martínez et al. (2009) evaluated the rotation of melon and tomato crops in almond shell substrates and concluded that this material can be used with up to 695 days of prior use, provided substrate moisture and volume contraction are controlled.

The objective of the present study was two-fold: to evaluate different particle sizes of mezcal maguey bagasse and coconut powder and to assess their effectiveness as substrates for greenhouse tomato crops following prior use as a substrate in a growth container for varying amounts of time.

MATERIALS AND METHODS

The three experiments were performed at the Interdisciplinary Research Center for Integrated Regional Development, Oaxaca Unit (CIIDIR-IPN-Oaxaca). In all experiments, it was used residual bagasse from the mezcal industry that was provided by the distiller Antequera Siglo XXI, Mitla Oaxaca, Mexico, and had been stacked at the distillery for four months. Without any processing, the mezcal maguey bagasse was transferred to the research center, where it was stored in a cool and dry environment. This material was designated as new material having 0 days of use (DOU). Reused materials, on the other hand, were obtained from tomato crop cycles with 150, 300, or 400 days of culture and were designated as having 150, 300 or 400 DOU, respectively. These units crop were used directly without any pretreatment, simulating what would a local farmer. The three experiments were performed simultaneously from January to July 2009 in a multi-tunnel greenhouse. The crop used for culture was *L. esculentum* Mill. cv "Don Raul", a tomato cultivar characterized by an indeterminate growth habit, a "pear" fruit type and a 150-day cycle. The tomatoes were planted in black polypropylene 18-L bags and fertilized through irrigation with the nutrient solution described by Urrestarazu (2004). In Experiment 1, four mezcal maguey bagasse materials with different usage times, 0, 150, 300, and 400 DOU, were evaluated and compared with standard commercially available peat substrate (trade name Sphagnum® Acadian Peat Moss, New Brunswick, Canada) as a control. A randomized complete block design was used with five blocks per treatment.

In Experiment 2 evaluated the interaction between particle size and usage time of the new or reused substrate. Three mezcal maguey bagasse particle sizes were used: fine (0.42–1.18 mm), medium (1.19–2.0 mm) and coarse (2.10–4.75 mm). The usage times are as described for Experiment 1: 0, 150, 300 and 400 DOU. A block experiment was designed in a split-plot arrangement with a total of twelve treatments and six blocks per treatment.

In Experiment 3 evaluated and compared production with different particle sizes of mezcal maguey bagasse waste material and coconut fiber material as substrates. The particle sizes of the two materials are as described for Experiment 2. The original coconut fiber material (a mixture of powder and fiber) was obtained from the mesocarp of the coconut palm fruit (*Cocos nuccifera* L.) from the coastal region of Oaxaca and processed in the mechanical engineering workshop of CIIDIR-OAXACA-UNIT. A randomized complete block design was used with a total of eight treatments and five blocks.

To analyze the effects of different particle sizes of the tested materials, the methodology proposed by Richards et al. (1986) and Martinez (1992) were used. The following parameters were measured and analyzed: total yield (kg plant^{-1}) of commercial and non-commercial fruits according to EU regulation L 100/11 (OJUE, 2001); external firmness using a fruit pressure tester (Penetrometer FT 327. 0–13 kg) Bertuzzi, Italy for the evaluation of fruit quality; and total soluble solids using a refractometer (N-1E, 0-11% Brix Atago USA, Inc.). For data analysis, analysis of variance and Tukey's test ($P \leq 0.05$).were performed using SAS software version 9.0 (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Experiment 1. The Effect of Usage Time of Mezcal Maguey Bagasse Substrate for Soilless Tomato Culture

Tomato plants grown on a reused substrate with 150 DOU produced the significant highest yields (2147 g plant^{-1}), the highest number of commercial quality fruit (18.2 fruits plant^{-1}) and the lowest number of non-commercial quality fruit (1.8 fruits plant^{-1}) (Table 1; Figure 1). The significant poorest performance and lowest number of commercial quality fruit were obtained with new substrates (0 DOU). In this regard, Urrestarazu (2004) mentions that an organic substrate that has not been composted may have several problems, including phytotoxicity, nitrogen immobilization and oxygen deficiency, that may affect proper plant nutrition and cause low yields. The production from plants grown in Sphagnum peat substrate

TABLE 1 Effect of usage time of mezcal maguey bagasse substrate on tomato production and fruit quality

	Production			Production	
Usage time (days)	Yield (g plant^{-1})	Commerials (fruits plant^{-1})	Non-commerials	Firmness (kg cm^2)	TSS (° Brix)
0	1039 c	6.8 c	6.6 a	4.2 b	4.4 a
150	2147 a	18.2 a	1.8 d	5.1 a	4.1 a
300	2041 b	15.2 b	5.2 b	5.7 a	4.3 a
450	1537 b	11.4 b	4.0 c	4.3 b	4.3 a
Peat moss	1855 b	15.2 b	4.8 b	5.1 a	4.3 a

Values with different letters indicate statistically different means (Tukey's test, 0.05); TSS: total soluble solids.

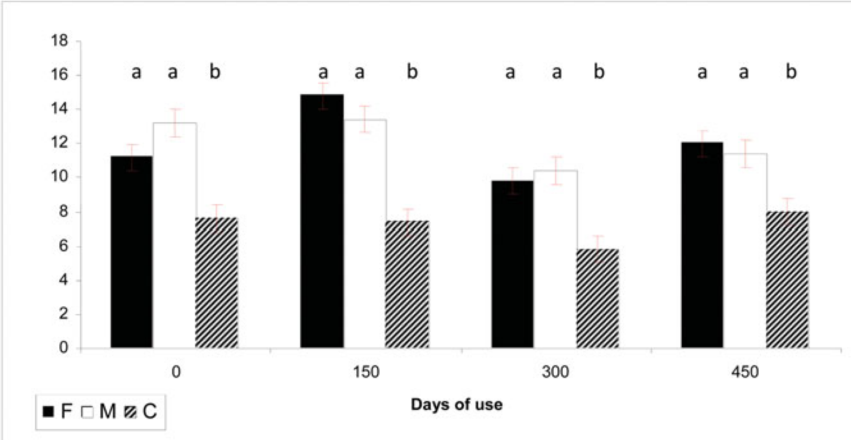

FIGURE 1 Effect of particle size and usage time of mezcal maguey bagasse substrate on commercial fruit production of tomato (fruit plant^{-1}). F: fine particles (1.18–0.425); M: medium particles (2.0–1.19 mm); C: coarse particles (4.75–2.1 mm); mm). Values with different letters indicate statistically different means (Tukey's test, $P \leq 0.05$). Vertical columns indicate standard errors.

was intermediate (1855 g plant^{-1}), relative to all test conditions, and similar to production from plants grown on 300 DOU maguey bagasse substrate. This similarity is likely due to the fact that peat is a heavily composted plant material in its place of origin (Puustjarvi, 1994). In general, the results show a significant tendency for decreased performance and a reduction in the number of commercial tomato fruits when the usage time of the maguey bagasse substrate was increased from 150 to 450 DOU. No significant differences were observed for fruit quality, as measured by firmness and total soluble solids content. The firmness values ranged between 4.2–5.7 kg cm^{-2}, which are higher than those obtained by Martínez-Gutiérrez et al. (2012) for tomatoes grown in rockwool and almond shells. The values of total soluble solids ranged between 4.1–4.4 °Brix, similar to those obtained by Urrestarazu et al. (2008) for tomatoes grown in vegetable waste compost with 135 DOU as a substrate.

Experiment 2. Effect of Particle Size and Usage Time of Mezcal Maguey Bagasse Substrate

Although no differences were observed between plants grown on fine or medium maguey bagasse particles, their production contrasted sharply with that on coarse particles, which showed the lowest number of fruits per plant and lower total production. Plants grown on substrates with 150 DOU and medium or fine particles showed the highest number of commercial quality fruits (14.8 fruits plant^{-1}), whereas the lowest number of commercial quality fruits (5.8 fruits plant^{-1}) was obtained when mezcal maguey bagasse with 300 DOU and coarse particle size were combined.

TABLE 2 Effect of particle size of the mezcal maguey bagasse and coconut fiber substrates on tomato production and fruit quality

Particle size	Production: Yield (g plant^{-1})	Commercials (fruits plant^{-1})	Non-commercials	Quality: Firmness (kg)	TSS (° Brix)
		Maguey bagasse			
Fine	1390 b	11.2 b	2.6 a	5.6 a	4.4 a
Medium	17234 a	13.2 b	3.4 a	4.2 a	4.5 a
Coarse	15032 a	7.6 b	1.8 a	3.9 a	4.3 a
Unsifted	1039 b	6.8 c	6.6 a	4.2 a	4.4 a
		Coconut fiber			
Fine	1641 b	13.8 a	1.6 a	5.4 a	4.2 a
Medium	1543 b	11.8 b	4.0 a	5.1 a	4.1 a
Coarse	891 c	6.8 c	2.8 a	5.0 a	4.2 a
Unsifted	1014 b	7.2 c	4.4 a	5.4 a	4.2 a

Values with different letters indicate statistically different means (Tukey's test, $P \leq 0.05$); fine (1.18 to 0.425 mm); medium (2.0 to 1.19 mm); coarse (4.75 to 2.1 mm); TSS: total soluble solids.

Increased particle size and usage time of the substrate resulted in a decreased amount of marketable fruit and total yield (Martínez et al., 2009). This decrease in production can be attributed to the lower water retention of a substrate with large particles, resulting in water and fertilizer through irrigation salt runoff and limiting their usage by plants (Ansorena, 1995). Similarly, as a substrate "ages" with use, the large majority of its physical properties are modified (Urrestarazu et al., 2008), with some increasing and others decreasing. This process has been demonstrated by Urrestarazu et al. (2008) with vegetable waste compost and by Martínez et al. (2009) with reused almond shell substrate with 695 DOU. The quality of the tomato fruit was not affected by particle size or its interaction with the usage time of the mezcal maguey bagasse substrate. The firmness values ranged between 3.86–5.64 kg cm^{-2}, which are very similar to those reported by Urrestarazu et al. (2008).

Experiment 3. Effect of Maguey Bagasse and Coconut Fiber Particle Sizes.

Plants grown on medium-sized particles of mezcal maguey bagasse and fine particles of coconut fiber showed the highest yields, (1723 g plant^{-1}) and (1641 g plant^{-1}), respectively (Table 2). The lowest yield and lowest number of commercial fruits were obtained from plants grown on coarse particles (2.1–4.75 mm) of coconut fiber and maguey bagasse substrates. Both substrates showed similar production levels on unsifted material, 1038.6 g plant^{-1} for maguey bagasse and 1013.9 g plant^{-1} for coconut fiber; these values were higher than those obtained for production on coarse particles. This indicates that the sieving process for both substrates separates the "core", the fine particles that dramatically alter air-water interactions of the substrates (Martínez-Gutiérrez et al., 2012) and, consequently, crop nutrition. This material accounts for 34–56% of mezcal maguey bagasse, depending on the extraction process used (Iñiguez et al., 2011), and 15–20% of coconut fiber, depending on the origin.

The largest numbers of commercial quality fruit were obtained from tomato plants grown on fine coconut fiber particles (13.8 fruits plant^{-1}) and medium-sized maguey bagasse particles (13.2 fruits plant^{-1}). The lowest numbers were observed on the unsifted materials for both substrates and on coarse particles of coconut fiber. No significant differences for the number of non-commercial quality fruits, firmness and total soluble solids. The values for the last two parameters were within the range of reference levels described by Urrestarazu et al. (2008).

The production and quality of tomato plants grown on fine, medium-sized, and coarse particles showed similar trends on coconut fiber or mezcal maguey bagasse substrates with 0 DOU. With increased particle size, the yields and the amount of commercial quality fruit decreased. This result can be attributed to an increase in total pore space and a reduction of small pores where water can be retained; moisture and dissolved salts are therefore drained and hardly used by the plants (Ansorena, 1995). Abad et al. (2002) reported that the optimum coconut fiber particle size is 0.2 to 0.5 mm. These values were encompassed by the range of sizes analyzed in the present study, and corresponding results were obtained.

CONCLUSIONS

The usage of mezcal maguey bagasse with 150 DOU and a fine particle size (1.18 to 0.425 mm) as a substrate for soilless culture of tomato produces higher yields per plant and a larger number of commercial quality fruits without affecting fruit quality.

Similar trends were observed for coconut fiber and mezcal maguey bagasse, with improved performance using fine and medium-sized particles.

The material proposed to obtain an equivalent result of peat moss for at least one time 230 days.

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