The Effects of Soilless Substrates on Sweet Chili Pepper Growth and Production

By

Rose Frethude Altema

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In

AGRONOMY

AGROENVIRONMENTAL SCIENCE DEPARTMENT

UNIVERSITY OF PUERTO RICO

MAYAGÜEZ CAMPUS

2018

Approved by:

______________________________ ____________________
Linda Wessel-Beaver, Ph.D. Date
Member, Graduate Committee

______________________________ ____________________
Lizzette González Gill, Ph.D. Date
Member, Graduate Committee

______________________________ ____________________
Angela M. Linares Ramírez, Ph.D. Date
President, Graduate Committee

______________________________ ____________________
Eric Harmsen, Ph.D. Date
Representative, Graduate School

______________________________ ____________________
Roberto Vargas Ayala, Ph.D. Date
Interim Director, Dept. of Agroenvironmental Sciences

ABSTRACT

Sweet chili pepper (*Capsicum chinense* Jacq.) is one of the principal components of the local cuisine of Puerto Rico. Considering the scarcity of land appropriate for field production in mountainous areas of Puerto Rico, soilless alternatives for production of sweet chili pepper should be considered. This study evaluated five substrates (1) PRO-MIX® BX (BX), (2) PRO-MIX® BX + Mycorrhizae (BX+Myco), (3) Coconut fiber (COCO), (4) PRO-MIX® High porosity + Mycorrhizae (HP+Myco) and (5) PRO-MIX® High porosity + Mycorrhizae + Biofungicide (HP+Myco+Fung) with the potential of being used in container production of sweet chili pepper in Puerto Rico, and four new cultivars of sweet chili pepper ('Bonanza', 'Carnaval', 'Amanecer' and 'Pasión'). Two plantings (Experiment I and II) using a factorial design (5 substrates x 4 cultivars) were carried out in 2017 and 2018. In general, differences between substrates were not affected by cultivar; substrate x cultivar interactions were either ordered or not significant. Plants in Experiment II were much more productive. The best substrates or cultivars in Experiment I were not always the best substrates or cultivars in Experiment II. BX produced plants with the highest number of fruits and fruit weight per plant and the largest average fruit weight in Experiment I, while BX, BX+Myco and HP+Myco+Fung produced equally productive plants in Experiment II. 'Bonanza' was the most productive cultivar in Experiment I, while 'Amanecer' was superior in Experiment II. This research suggests that, based on its lower cost, BX would be a good choice for soilless production of sweet chili pepper. For sweet chili pepper production in pots, 'Amanecer' and 'Bonanza' would be better cultivar choices than 'Pasión' and 'Carnaval'.

RESUMEN

Ají dulce (*Capsicum chinense* Jacq.) es uno de los componentes principales de la cocina local de Puerto Rico. Teniendo en cuenta la escasez de tierra apropiada para la producción en el campo en áreas montañosas de Puerto Rico, deben considerarse alternativas sin suelo para la producción de *ají dulce*. Este estudio evaluó cinco sustratos (1) PRO-MIX® BX (BX), (2) PRO-MIX® BX + Mycorrhizae (BX+Myco), (3) fibra de coco (COCO), (4) PRO-MIX® High porosity + Mycorrhizae (HP+Myco) y (5) PRO-MIX® High porosity + Mycorrhizae + Biofungicide (HP+Myco+Fung) con el potencial de ser utilizado en la producción en tiestos de *ají dulce* en Puerto Rico, y cuatro nuevos cultivares de *ají dulce* ('Bonanza', 'Carnaval', 'Amanecer' y 'Pasión'). En 2017 y 2018, se llevaron a cabo dos plantaciones (Experimento I y II) con un diseño factorial (5 sustratos x 4 cultivares). En general, las diferencias entre los sustratos no fueron afectadas por el cultivar. Las interacciones sustrato x cultivar fueron ordenadas y no significativas. Las plantas en el Experimento II fueron mucho más productivas. Los mejores sustratos o cultivares en Experimento I no siempre fueron los mejores sustratos o cultivares en Experimento II. BX produjo plantas con el mayor número de frutas, peso de frutos por plant y el mayor peso promedio de fruto en Experimento I, mientras que BX, BX+Myco y HP+Myco+Fung produjeron plantas igualmente productivas en Experimento II. 'Bonanza' fue el cultivar más productivo en Experimento I, mientras que 'Amanecer' fue superior en Experimento II. Esta investigación sugiere que, en base a su menor costo, BX sería una buena opción para la producción de *ají dulce* en envases. Para la producción de *ají dulce* en macetas, 'Amanecer' y 'Bonanza' serían mejores opciones de cultivo que 'Pasión' y 'Carnaval'.

ACKNOWLEGEMENTS

The time is come to humble myself before the Lord with a spirit of gratitude to say thanks for the opportunity He gives me to accomplish my thesis research project.

I also thank my wonderful husband, Antoine Luckner Sanon who has supported me morally taking care our two kids (Marc Benslee Sanon and Mitt Ruben Sanon) and intellectually all along my study career at the University of Puerto Rico Mayaguez (UPRM) Campus.

Thanks are owed to my advisor, Dr. Angela M. Linares, from one part to the other part who has provided scientific and financial support for me to be able to conduct this challenging research accomplishment. I love you my dear, may the Supernatural bless you abundantly.

In addition, I would like to thank the other members of my graduate committee, Dr. Linda Wessel Beaver, Dr. Lizzette Gonzalez Gill, for their contributions throughout the research project. Dr. Linda B. being outside of Puerto Rico had always been so cooperative to me during that process and sometimes she wrote to encourage me to work harder and harder to accomplish the research project. Remember, I had to be out of Puerto Rico to write my thesis because of the finance situation at a given time.

Furthermore, I would like to say thanks to Mr. José Ariel Muñoz, Administrator of the campus Laboratory Farm “Finca Alzamora’’, Wilfredo Seda and Magdiel Miranda graduate students at the Mayaguez University Campus, for their collaboration. Sincerely, without their helping hands put into the lab works during my experimentation, the accomplishment of the thesis project would not be a reality today.

Finally, I would like to send a sincere appreciation and thanks to every single professor and personnel of the UPRM who contributed to my academic and professional growth, particularly Dr. Carlos Rosario, Dr. Christopher M. Papadopoulos, Dr. Angel Luis Gonzalez, Dr. Raul Macchiavelli and Dr. Morales Payán.

This research was supported in part by Hatch project accession no. 1000526 from the USDA National Institute of Food and Agriculture and HATCH-458.

Table of Contents

List of Tables

List of Figures

1. Justification

Sweet chili pepper (*Capsicum chinense* Jacq.) is one of the five domesticated species of the genus *Capsicum* and may be a progenitor of other species (Eshbaugh, 1993). Fruits are generally small to medium in size, averaging 2-7 cm in diameter and 2-10 cm in length. The Amazonian South America is the center of diversity of *C. chinense* and the species later spread into the Caribbean. Although *C. chinense* species originated in the New World; a French taxonomist named it in 1776 who thought it came from China. It is called *ají dulce* in Puerto Rico and is one of the principal components in the local cuisine, extremely aromatic with a fruity fragrance and a sweet flavor. In Puerto Rico, Cuba and the Dominican Republic it is used to season dishes and it is one of the most important ingredients for *sofrito* (Mangan et al., 2008).

Vegetables contributed about 13% of the value of crops in Puerto Rico with an economic contribution of $46.93 million to the gross domestic product of the island, according to the most recently available statistics from 2015/16 (Department of Agriculture Puerto Rico, 2016). Tomatoes are the vegetable of greatest economic importance, contributing $19.98 million. Among the remaining vegetables, peppers *C. annuum*, such as cooking and bell types, are among the crops with the highest economic importance with a value of $2.92 million. Sweet chili pepper has a similar value: $2.185 million from a total production of 41.26 million hundredweight (cwt). The unit value of the crop at the time of the Department of Agriculture (2016) report was $115.89/cwt. At the current time, the farm-level value of sweet chili pepper may be as much as $150/cwt, making it an extremely high-value crop on a unit area basis (L. Wessel-Beaver, personal communication).

Many parts of the world have suffered for decades from a considerable reduction in land dedicated to agriculture due to increasing population, construction and so on. To respond to the market demands of horticultural crop production outside of traditional field production, growers have used organic and inorganic substrates like perlite, rock wool, coconut fibers, peat, vermiculite, gravels, and sand in vegetable production (Butt et al., 2007). These alternative-growing mediums can potentially have a positive effect on the yield and the quality of important horticultural crops in the market place. The use of substrates causes no land degradation, minimizes the chances of environmental pollution, is economical in terms of water consumption, makes it easier to control plant nutrients, allows early harvest of crops, requires little or no expenses of media sterilization and requires no fallow period after harvesting the crop. Most of the commercial potting mixes used for pepper production are peat-based media with additives to improve texture, wettability, pH, and fertility (Kelly et al., 2009).

In Puerto Rico sweet chili pepper (*ají dulce*) is mostly produced conventionally, that is, the plants are grown in fields. However, there are number of challenges to production of sweet chili pepper in the mountains of Puerto Rico. Farms are small, and there is limited access to flat land. Considering the scarcity of land appropriate for field production in the mountainous areas of Puerto Rico, soilless alternatives for vegetable crop production should be considered. Sweet chili pepper has a high economic value that could potentially offset the expenses of containers and substrates. Therefore, this thesis research project evaluates the effects of different soilless substrates on the production and growth of sweet chili pepper.

2. Objectives

Evaluate five substrates with the potential of being used in sweet chili pepper container production in Puerto Rico.

Evaluate the container production performance of four cultivars of sweet chili pepper ('Bonanza', 'Carnaval', 'Pasión' and 'Amanecer') recently developed by the Agricultural Experimental Station (AES) of the University of Puerto Rico (UPR).

Study the potential cultivar by substrate interactions.

3. Literature Review

3.1 Overview

Bosland (1996) states that *Capsicum* spp. have been known since the beginning of civilization in the Western Hemisphere and have been a part of the human diet since 7500 BC. *Capsicum* spp. are known worldwide. They are members of the Solanaceae family and there are 27 species, although only five crop species, *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens* and *C. pubescens*, are of high economic value for food and spices, and are currently cultivated (López-Puc et al., 2006).

According to Eshbaugh (1993), there is a debate about the geography of the origin of *Capsicum* and the origin of the domesticated taxa of this species. Moscone et al. (2007) and Barboza and De Biem Bianchetti (2005) indicated that the determination of the place of origin of the genus and each of the domesticated species as a problematic exercise. Mostly the debate concerns the origin of domesticated species of *Capsicum*. Four regions of distribution are known for *Capsicum:* southern USA and Mexico to western South America (Peru) with 12 species; northeastern Brazil and coastal Venezuela (1 species); eastern coastal Brazil (10 species);

Southeastern (2 species) and central Bolivia and Paraguay to northern and central Argentina (8 species). Brazil has the largest concentration of *Capsicum* species (13).

According to FAO, the annual world production of fresh peppers from the years 1992 to 2012 increased by almost fourfold, from approximately 8.2 to about 31.2 million tons. This augmentation was in East Asia, especially in China, where at the same period of time annual production increased by eightfold, from about 2.3 to about 16 million tons (Pickersgill, 2003).

The Department of Agricultural of Puerto Rico (2016) has statistical data available on the production of sweet chili pepper. That data is summarized in Table 1. In general, there has been an increase in sweet chili pepper production especially since 2013. This may be due to the increased demand for local products in Puerto Rico which has resulted in increased value of the crop.

Table 1. Statistics on sweet chili pepper production in Puerto Rico according to the Puerto Rico Department of Agriculture (2016).

Year	Production (cwt x10^6)	Price/unit ($)	Value ($' 000)
1997-98	9.700	75.59	733
2009-10	7.569	113.34	858
2010-11	3.442	179.78	619
2012-12	9.523	171.48	1,633
2012-13	9.872	151.34	1,494
2013-14	16.019	133.53	2,139
2014-15	18.859	115.89	2,185

cwt = hundredweight (100 lbs)

3.2 Substrates

Burés (1997) defines a substrate as any medium that is used for growing plants in containers. The culture of substrates was commonly known by 1973 when the Danish rockwool-industry publicized their hydrophilic GRODAN-rock wool as a horticultural substrate for plant propagation and precision growing. Rockwool is an inorganic material made from spinning fiber from molten basalt and chalk that is now commonly used in hydroponic production. The substrate culture has become the most important growing alternative, and is used in more than 60% of the glasshouse acreage in the Netherlands and 50% of the glasshouse acreage in Belgium and France (Butt et al., 2007). However, Holland is considered to be the leading country in the use of soilless culture technology by using various kinds of organic and inorganic substrates. Central Europe, Canada, Russia, USA, Japan, Korea Jordan, Mexico and China recognize the importance of using substrates for agricultural production. Substrates now occupy 50,000 hectares of crop production in those countries (Butt et al., 2007).

Jovicich et al. (2003) indicate that most greenhouse pepper crops in Florida are grown in soilless culture. A greenhouse production system of pepper differs greatly from the traditional field pepper cultivation system where plants are grown on polyethylene-mulched beds with drip irrigation. The use of greenhouses in crop production has advanced over the decades and has usually been accompanied with the development of soilless culture systems (SCSs) since it is the method of production that is often the most intensive and effective. SCSs guarantee flexibility and intensification and provide high crop yield and high-quality products (Gruda, 2009).

Soilless culture or aggregate culture is the system where the nutrient solution is supplied to plants by an irrigation system through the media (pumice, rockwool, perlite, sand, gravel, etc.) and the solution is allowed to run to waste or the solution is recirculated (Olympios, 1979). Many factors have to be taken into consideration when choosing a soilless media, it must drain freely with no restrictions to water flow, it must be easily aerated, it should have good water holding capacity, it should be non-toxic and free of weeds, pests, and chemicals and must be inexpensive (Jovicich et al., 2003). However, the ideal substrate would be one that provides the plant with the best conditions for its growth that has a low environmental impact and has cost/benefit ratio that is adequate for the production system in question (Valenzuela et al., 2014).

Sonneveld (2004) indicates that growing crops in substrate systems requires higher fertilization than growing directly in soil. Horticultural crops produced in substrates can have better market quality (Cruz-Crespo et al., 2013). Better usage of water and nutrients are another benefit gained from using substrates to produce crops.

Producing crops in soilless systems offers the advantages of increased productivity, better control of plant nutrients, water economy and control, reduction of labor requirement, reduction in sterilization practices, control of root environment, and multiple crops per year. However, this system has its flaws since it relies on high capital investment, increased technical demands on the management and an increased risk of disease infections (Olympios, 1979).

Gabriel et al. (2009) studied the effect of physical and hydraulic properties of peat moss and pumice on Douglas fir bark soilless substrates. They showed that peat and pumice interacted to affect physical properties. Total porosity increased from 85% to 89% while the level of peat moss increased from 0% to 30% and the total porosity decreased from 89% to 85% while the level of pumice increased. The interaction of peat moss and pumice were affected by decreased container capacity. Interaction between peat and pumice regarding their effects on substrate physical properties cannot be accurately predicted from the known properties of the components used in the substrate.

Substrates can vary from low porosity to high porosity depending on the materials used. Texture is important because it controls how well the soil can hold water and absorb it. Soils with small particles have larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water. Substrates that have coconut fiber have high water holding capacity and less air porosity. A substrate with only coarse components has many macropores, the air porosity is high and the water holding capacity is low. In contrast, a substrate with only fine components has many micropores, the substrate has low air porosity and the water holding capacity is high. High porosity allows more oxygen to the roots (Lopez, 2018).

Mycorrhiza are fungi that form a symbiotic association with plant roots, they can expand root surface and increase absorption capacity (Pereira et al., 2015). Commercial substrates are available that contain mycorrhizae and it is also possible for growers themselves to manually inoculate their own substrate mixes with mycorrhizae. Arbuscular mycorrhizal fungi (AMF) are capable of forming mycorrhizae with >80% of plant species, including most of the cultivated species. In the mycorrhizae association, fungi enhances the acquisition of soil mineral nutrients, particularly phosphorus (P) and nitrogen (N), as well as potassium (K), sulphur (S), magnesium (Mg), copper (Cu), zinc (Zn) and iron (Fe).

AMF are important in ecological agriculture because of the benefits they provide to the majority of crops by acting as biofertilizer, bioprotectors and biocontrol agents (Castillo et al, 2009). AMF species such as *Glomus aggregatum, G. interadices and G. mosseae* have provided positive effect on growth, yield and nutrition of plants whether grown conventionally or organically (Pereira et al., 2015). *Glomus interadices* is a mycorrhizal fungi species that colonizes the roots of most horticultural crops. It improves nutrients uptake, improving water absorption and increases plant tolerance to stresses, root disease and excessive salinity.

Some commercial substrates also contain biofungicides. Biofungicides are naturally based microbial or biochemical products derived from animals, bacteria, plants, or minerals. These products can affect fungal organisms directly or may stimulate the defense response of the plant

(Moyer and Peres, 2008). *Bacillus pumilus* is one example of a naturally occurring strain of bacteria that has been used commercially to enhance plant growth and combats harmful organisms such as *Fusarium, Pythium and Rhizoctonia* (Kloepper et al., 2004; Parent, 2018).

Tzortzakis and Economakis (2008) recommended that the use of low-priced local substrates with less pollution or residue production with adequate physical and chemical properties, instead of using imported substrates that have a tendency of showing deficiency symptoms. An over-optimum supply of nutrients can cause an undesirable accumulation of nutrients in the root environment of the plants in the pots or substrates related to osmotic or salinity problems.

Roldán (2015) evaluated the effect of humidity levels in three substrates on the growth and yield of sweet chili pepper hybrids under greenhouse conditions. The results showed that there is no effect due to amount of water supply on the plant's growth, although the hydric-stressed plants were the first to begin the flowering and fruiting phase, and also produced the highest commercial yield while reducing the water supply from 15% to 30% respectively of the control plants.

A growth analysis was conducted by Charlo et al. (2011) on sweet pepper cultivated in coconut fiber in the greenhouse. The experiment showed that the plant height reached a maximum of 136.9 cm at 189 days after transplanting, the number of floral buds was greatest at 42 days after seedling, and the number of fruits was greatest at 105 days after transplanting. The total production per plant was 3.9 kg/plant with the mean number of fruit per plant of 19.5 and average fruit weight of 200 g.

3.3 Insects and Diseases

According to Lowell et al. (1991) many diseases and insects like armyworm, whiteflies (various species), aphids (various species), and thrips (*Tysanoptera spp*) attack sweet chili pepper and other pepper species. *Spodoptera frugiperda* is a significant pest for vegetables growers because of its wide host range and resistance to most insecticides; the older larva may feed on the fruit and leaves. Aphids feed on new terminal growth and the underside of leaves. They cause both direct and indirect damage by removing plant fluids and they feed on new growth that may cause leaf yellowing and plant stunting. Thrips cause direct damage by feeding on pepper leaves reduce the ability of the plants to photosynthesize, reducing yield, and create silvery white streaks on the petals of flowers (Cloyd, 2016).

Pepper weevil (*Anthonomus eugenii* Cano) is one of the most important insect pests of pepper in the Southern United States (Capinera, 2017). It destroys the blossom buds and immature pods. Adult and larva of pepper weevil feeding causes bud drop. In the absence of blossom and fruit, adult feed on leaves and stem material of pepper. It allows penetration of the fungus *Alternaria alternata*, weak pathogen and extensive fungus growth within the pepper fruit.

Bacteria spot (*Pseudomonas spp*) has a wide geographic distribution occurring wherever pepper is grown under overhead irrigation or rain fed condition (Lowell et al., 1991). It spreads rapidly during warm and rainy weather. Bacteria wilt (*Ralstonia solanacearum*) is mainly a problem in tropical or subtropical climates with relatively high rainfall. It can cause substantial losses in pepper like wilting the youngest leaves at the ends of the branches during the hottest part of the day and discoloration of the vascular tissue. Cercospora leaf spot is very common and can cause defoliation under prolonged periods of wetness. It is worse during rainy periods because the bacteria are splashed from the soil onto the fruit which are more susceptible because of their high moisture content. Kelly et al. (2009) stated that *Tomato Spotted Wilt Virus* (TSWV) is one of the most common viruses that affect pepper in the southeastern United States. It is transmitted by thrips and thus can affect pepper at any stage of development. Estévez de Jensen et al. (2017) reported that *Tomato chlorotic spot virus* (TCSV) is a recent virus that affect commercial planting crops like vegetables and ornamental in the Caribbean and Florida. In Puerto Rico; TCSV was observed in tomato, bell pepper, lettuce and on leaves of sweet chili pepper.

An investigation was conducted to determine through interviews with growers, which fungal diseases had been affecting commercial production of vegetables crops on the southern coast of Puerto Rico over a period of 5 years (1996 to 2000) to identify in the laboratory the causal agents of fungal diseases found during the farm visits. They found that *Pseudoperospora cubensis* and *Erysiphe cichoracearum* causing downy mildew and powdery mildew respectively and *Dyclimella bryoniae* producing gummy stem blight. *Cyrynespora cassiicola* affecting cucumber. *Sclerotium rolfsii* affecting eggplant, pepper, tomato and beans (Ruiz-Sifre and Flores-Ortega, 1995).

4. Materials and Methods

This study consisted of a factorial combination of four cultivars of sweet chili pepper (‘Bonanza’, ‘Carnaval’, ‘Amanecer’ and ‘Pasión’) planted in five growing substrates: (1) coconut fiber (COCO), (2) PRO-MIX® BX (BX), (3) PRO-MIX® BX+ Mycorrhizae (BX+Myco), (4) PRO-MIX® HP+ Mycorrhizae (HP+Myco) and (5) PRO-MIX® HP + Mycorrhizae + Biofungicide (HP+Myco+Fung). These substrate treatments are described in Table 2. All substrates, except COCO, were commercial products from Primer Tech Horticulture (Quakertown, Pennsylvania).

Seeds of each of the four cultivars were planted in 72-cell plastic trays. Individual cells measured 3.2 cm wide at the top with a depth of 4.5 cm. All seeding trays were filled with BX. Trays were planted with two seeds per cell and thinned to a single seedling at approximately two weeks after seeding. The trays were placed in a greenhouse behind the Piñero Building at the University of Puerto Rico, Mayagüez Campus (UPRM). Plants were watered by hand as needed. A fertilizer solution with a concentration of 4 g of 20N-8.74P-16.6K (800 ppm N) in 1 liter of water was prepared. A total of 100 ml of this solution was added to each pot every three weeks beginning a week after transplanting. Seedlings were transplanted to 2.5 gallon plastic pots at approximately 6 to 8 weeks after seeding. A total of 20 pots were used for each of the five substrates for a total of 100 pots, experiment wise.

The substrates were moistened as needed and pots were filled to approximately 13 cm from the top. For each substrate five plants of each cultivar were transplanted into individual pots. Pots were labeled with the cultivar name and substrate treatment combination. Pots were arranged in a randomized complete block design with five replications. Each block contained the four cultivars by five substrates treatment combinations (4 x 5 factorial). The study was repeated two times, once in the summer months (Experiment I, June to October 2017) and once in the winter months

(Experiment II, December 2017 to May 2018). Experiment I was conducted on a terrace behind the Piñero Building. This location has some shading occurring later in the day that was caused by large trees near the experiment. Experiment II was conducted placing the pots on top of cement banks near the “Vita” UPRM campus entrance. This location has full sun during the entire day. The available space in Experiment II allowed the pots to be placed further apart compared to Experiment I.

Table 2. Description of experimental substrates.

Substrates	Description
Coconut fiber (COCO)	100% coconut fiber
PRO-MIX® BX (BX)	75-85% Sphagnum moss Perlite Vermiculite Limestone (to adjust pH) Wetting agent
PRO-MIX® BX + Mycorrhizae (BX+Myco)	75-85% Sphagnum moss Perlite Vermiculite Limestone (to adjust pH) Wetting agent *Glomus intraradices*
PRO-MIX® HP + Mycorrhizae (HP+Myco)	65-75% Sphagnum moss Perlite Limestone (to adjust pH) Wetting agent *Glomus intraradices*
PRO-MIX® HP + Mycorrhizae + Biofungicide (HP+Myco+Fung)	65-75% Sphagnum moss Perlite Limestone (to adjust pH) Wetting agent *Glomus intraradices* *Bacillus pumilus* (GHA180)

The following variables were measured: height of the plants, number of days from transplant to flowering, number of days from transplant to harvest, number and weight of fruits per plant per harvest and average fruit weight. Height was measured every two weeks beginning approximately three weeks after transplanting. Plants were measured using a plastic PVC tube with graduations in centimeters. Days to flowering was noted as the number of days from transplant to the appearance of the first open flower. Harvesting began when the fruits began to turn from green to orange or red color. Harvesting was done on a weekly basis or as needed. At each harvest, the number of fruit and fruit weight per plant were recorded. Average fruit weight at each harvest was determined by dividing the total fruit weight by total number of fruit. At the end of Experiment II a single plant of each combination of cultivar and substrate was pulled from its pot. The roots were washed and a photograph of each roots mass was taken.

Although both Experiment I and II were arranged as randomized complete block designs, the data was analyzed using a one-way analysis of variance (ANOVA) in InfoStat (Di Rienzo et al. 2018) because of the occurrence of missing plants. About 30% of the data was missing in Experiment I due to dead plants. In Experiment II only a few plants died. Each experiment was analyzed separately using factorial analysis (4 cultivars x 5 substrates) with five repetitions. Substrate and cultivar means were compared using Fishers Least Significant Difference.

5. Results

5.1. Experiment I

Since the ANOVA indicated that no significant substrate x cultivar interactions were observed for plant height when measured from 29 days to 189 days after transplanting (Table 3), it was possible to directly study the main effects of substrates and cultivars. There were significant differences among substrates and among cultivars at each date that the plant height was measured. CVs at 49 to 189 days after transplanting were higher compare to CVs at 29 days after transplanting.

The height of plants planted in HP+Myco, COCO and BX+Myco was significantly shorter (13.0 to 13.7 cm) than plants in BX (18.4 cm) and HP+Myco+Fung (16.2 cm) at 29 days after transplanting (Figure 1). The same trend continued at 49 days after transplanting at which time plants in BX exhibited the highest plant height (25.3 cm). From 70 to 189 days after transplanting there were no significant differences in height for plant in HP+Myco and COCO and these two treatments resulted in the shortest plants. There were no significant differences in plant height among the other three substrates that produced the tallest plants. At 189 days after transplanting (almost 7 months), plant height ranged from 33.3 cm to 37.5 cm for COCO and HP+Myco and 61.1 cm to 64.0 cm for HP+Myco+Fung and BX and 57.2 cm for BX+Myco.

At 29 days after transplanting no significant difference was observed in plant height for the two shortest cultivars, ‘Bonanza’ (13.9 cm) and ‘Carnaval’ (14.0 cm), nor between the two tallest cultivars, ‘Amanecer’ (15.9 cm) and ‘Pasión’ (16.0 cm) (Figure 2). At 49 days after transplanting there were no significant difference observed between ‘Amanecer’ (18.7 cm), ‘Bonanza’ (19.6 cm) and ‘Pasión’ (20.3 cm), and these cultivars were significantly taller than ‘Carnaval’ (14.8 cm).

Table 3. Sources of variation, degrees of freedom, probability values in F-test and coefficient of variation (CV) for plant height in four cultivars of *Capsicum chinense* grown in five planting substrates in Experiment I (June to October, 2017)

		Days after transplanting						
Sources of variation	Degrees of freedom	29	49	70	97	126	157	189
Planting substrate (S)	4	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar (C)	3	0.0037	0.0079	0.0027	<0.0001	<0.0001	<0.0001	<0.0001
S x C	12	0.2332	0.1392	0.8319	0.4094	0.4374	0.6350	0.6914
CV (%)		17.7	27.1	36.7	29.9	29.9	33.5	34.8

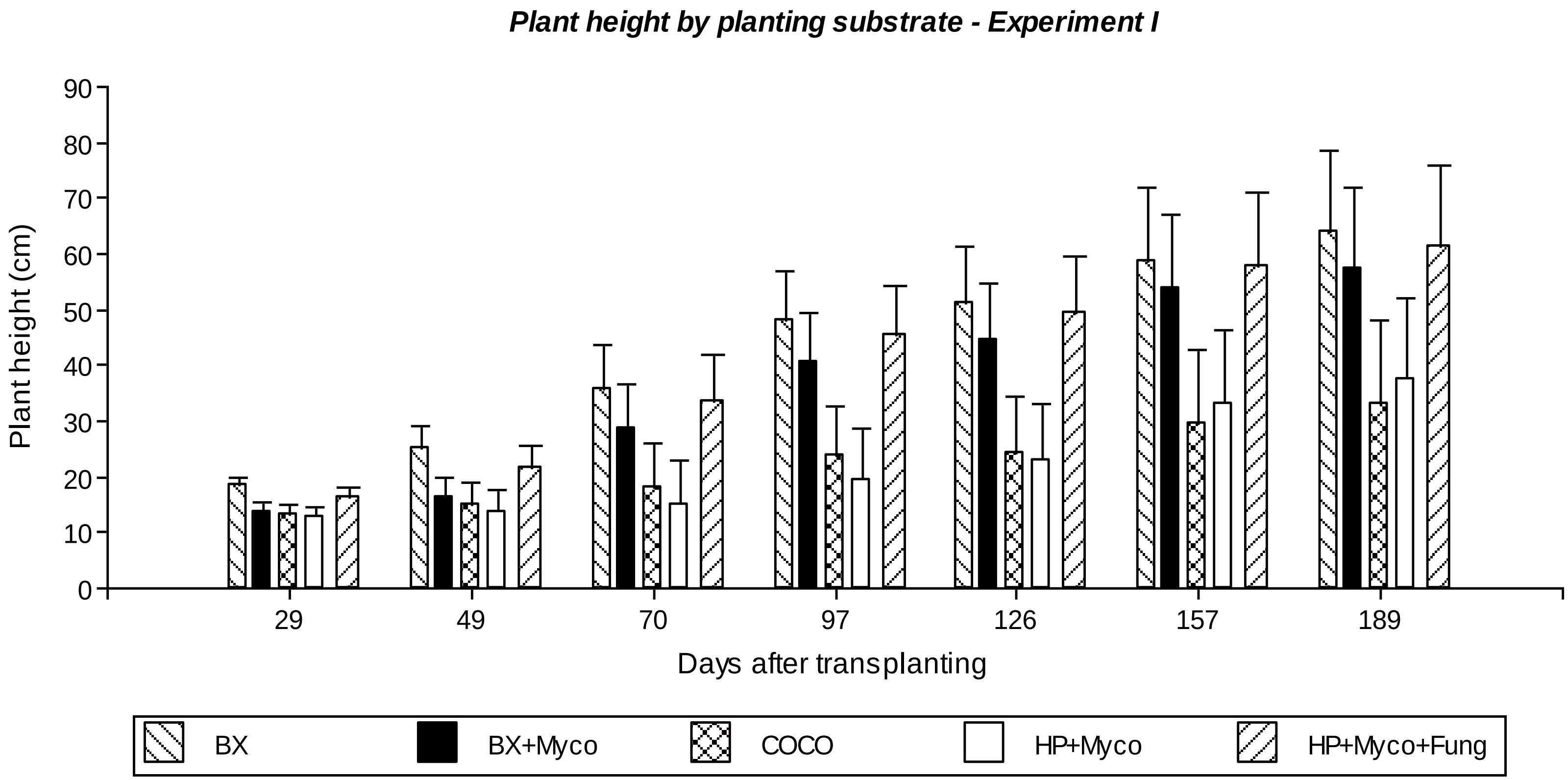

Figure 1. Mean plant height of *Capsicum chinense* planted in PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco) and PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). The mean of each substrate was averaged over four different cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

At 70 days after transplanting ‘Bonanza’ was the tallest cultivar and ‘Pasíon’ was significant shorter than ‘Bonanza’. From 97 to 189 days after transplanting plants of ‘Bonanza’ and ‘Pasíon’ were always significantlty taller than ‘Carnaval’ and ‘Amanecer’. At 189 days after transplanting ‘Pasíon’ measured 65.5 cm and ‘Bonanza’ measured 64.9 cm. In contrast, ‘Amanecer’ measured 39.1 cm and ‘Carnaval’ measured 33.0 cm.

The ANOVA for total number of fruit, total fruit weight and average fruit weight indicated significant substrate x cultivar interactions (Table 4). However, since the interactions were generally ordered (that is, relative differences between substrates were similar for all four cultivars), the main effects of substrate and cultivar are presented here. There were significant differences between planting substrates and between cultivars for number of fruit, total fruit weight and average fruit weight. The CVs of total fruit weight and average fruit weight were higher compared to the CV for number of fruits indicating there was more variability in total fruit weight and average fruit weight than total fruit per plant. In general, the CVs in Experiment I was very high (120.7 - 172.2).

Table 4. Sources of variation, degrees of freedom, probability values in F-test and coefficient of variation (CV) for total number of fruit, total fruit weight and average fruit weight in four cultivars of *Capsicum chinense* grown in five planting substrates in Experiment I (June to October 2017).

		Probability (F-test)		
Sources of variation	Degrees of freedom	Total number of fruit per plant	Total fruit weight per plant	Average fruit weight
Planting substrate (S)	4	<0.0001	<0.0001	<0.0001
Cultivar (C)	3	<0.0001	<0.0001	<0.0001
S x C	12	<0.0001	<0.0001	<0.0001
CV (%)		120.7	137.3	172.2

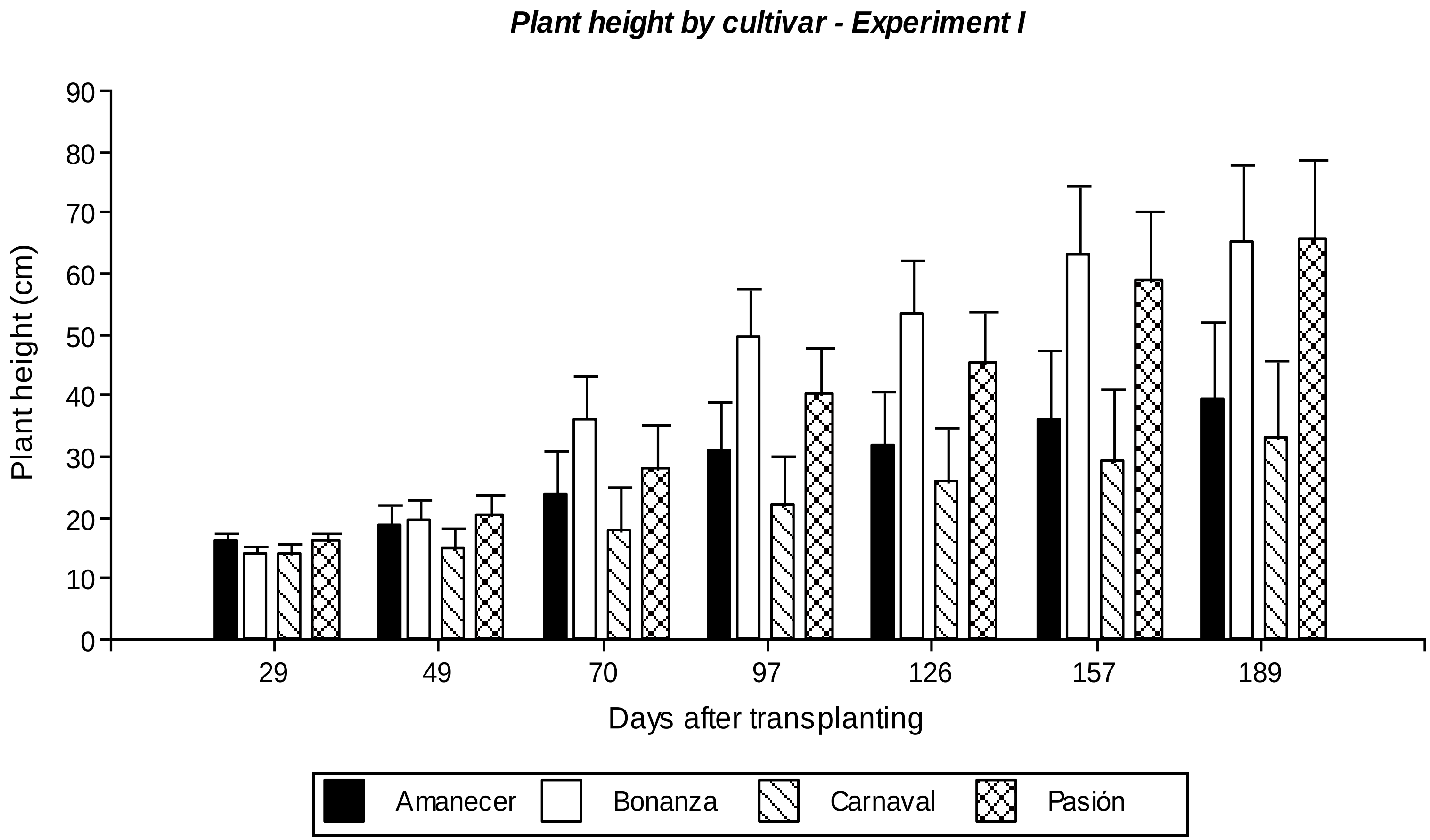

Figure 2. Mean plant height of four cultivars (‘Amanecer’, ‘Bonanza’, ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

BX was the substrate with the highest number of fruits per plant (24.9) (Figure 3). Plants in this substrate produced about twice as many fruits as plants in the next best substrate, HP+Myco+Fung, with 13.7 fruits per plant. The other three substrates performed very poorly. Plants in COCO substrate produced few or no fruit.

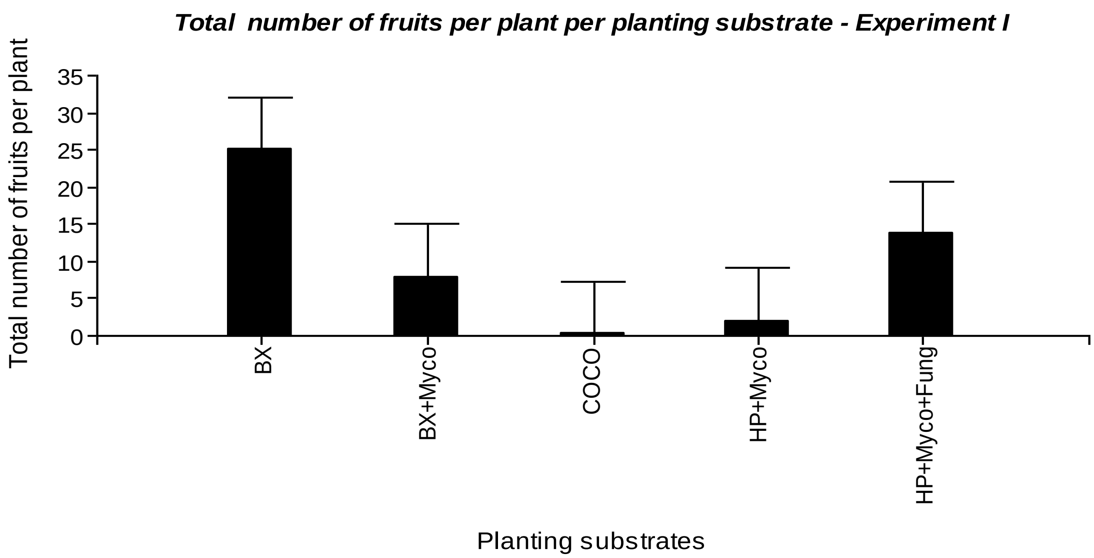

Figure 3. Mean total number of fruit per plant of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco, Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco), PRO-MIX®High porosity+Mycorrhizae+Biofungicide (HP+Myco+Fung). The mean number of fruit per plant was averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

'Bonanza' was the cultivar with the highest total number of fruit per plant (21.9) (Figure 4). There was no significant difference in the number of fruits produced by 'Amanecer' (7.9) and 'Pasión' (7.6). 'Carnaval' produced the lowest number of fruit per plant (1.5).

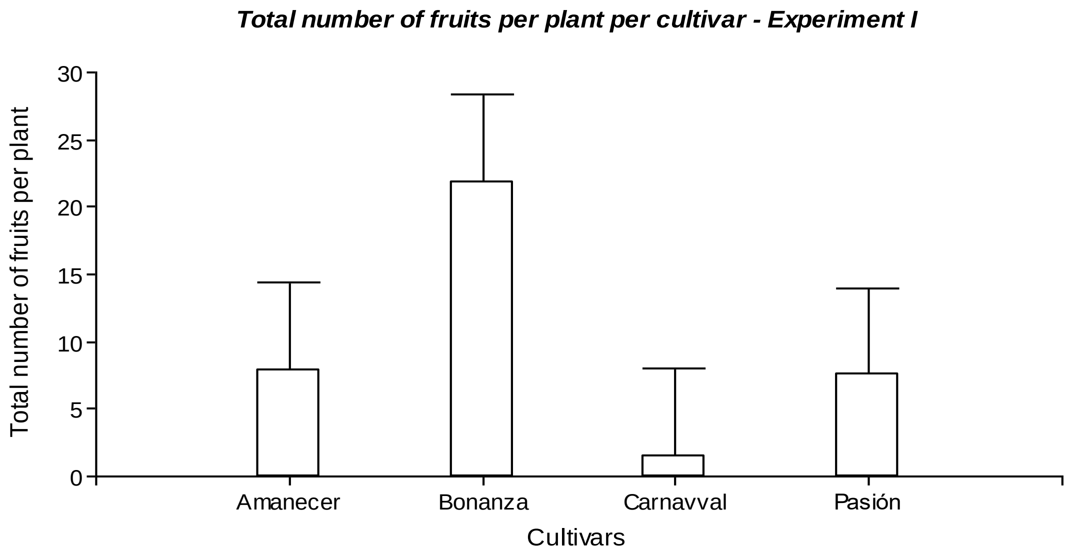

Figure 4. Mean total number of fruit per plant of four cultivars (‘Amanecer’, ‘Bonanza’, ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

Plants in BX produced the highest total fruit weight per plant (257.4 g) followed by HP+Myco+Fung (128.2 g) and BX+Myco (91.6 g). The latter two substrates were not significantly different (Figure 5).

Plants in COCO substrate produced almost no fruit. ‘Bonanza’ was the cultivar with the highest total fruit weight (272.0 g) (Figure 6). There was no significant difference among the other three cultivars which had fruit weight per plant varying from 14.1 to 60.4 g.

Figure 5. Mean total fruit weight per plant (g) of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco, Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco, PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). The mean of total fruit weight per plant was averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

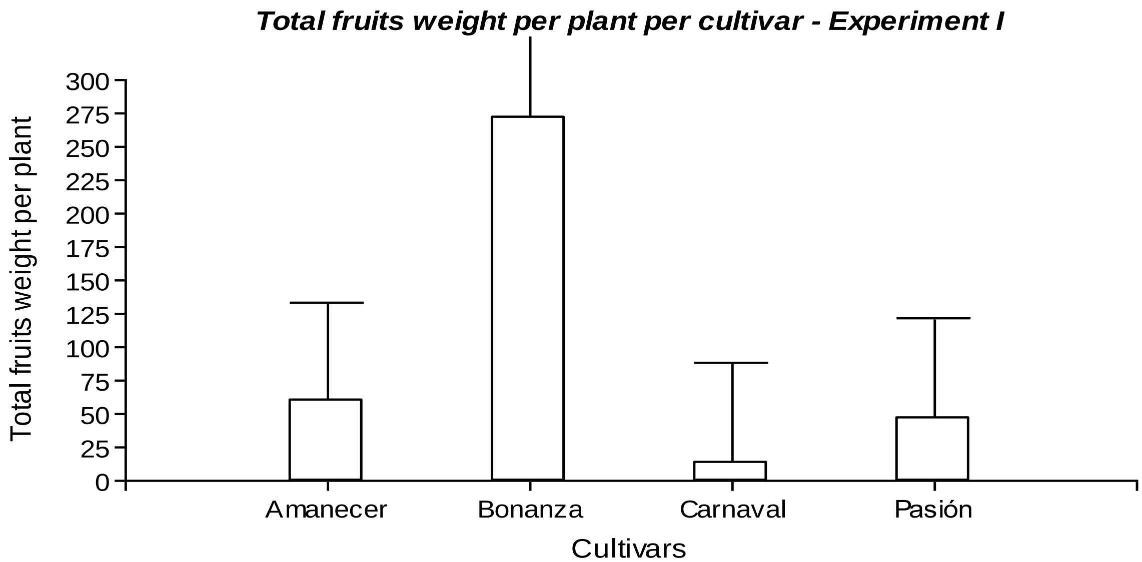

Figure 6. Mean total fruit weight per plant (g) of four cultivars (‘Amanecer’, ‘Bonanza’, ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

BX was the substrate with the highest average fruit weight (4.4 g) followed by HP+Myco+Fung (2.7 g) and BX+Myco (1.7 g) (Figure 7). There was no significant difference between HP+ Myco (0.4 g) and COCO (0.05 g).

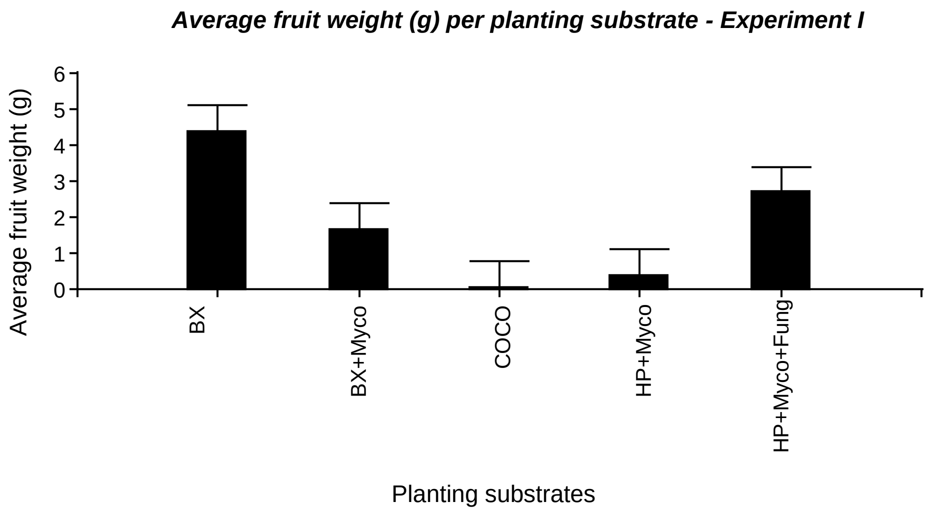

Figure 7. Average fruit weight of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco) and PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). Average fruit weight of each substrate was averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

'Bonanza' was the cultivar with the highest average fruit weight (4.5 g) followed by 'Amanecer' (1.3 g) and 'Pasión' (1.1 g) which did not different from each other (Figure 8). 'Carnaval' had the lowest average fruit weight (0.4 g)

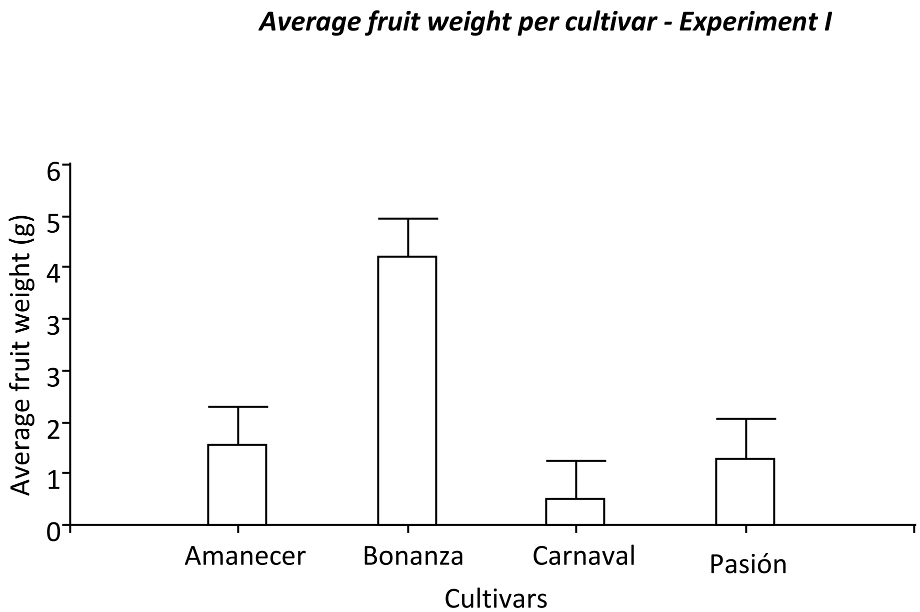

Figure 8. Average fruit weight of four cultivars (‘Amanecer’, ‘Bonanza’ ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The average fruit weight of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment I June to October, 2017)

Generally, in Experiment I the plants were affected by the symptoms of foliar diseases, insects and maybe by the inappropriate planting site. Experiment I was conducted during the hot, rainy season in Puerto Rico which likely also contributed to the poor yields in this Experiment. Figure 9 and 10 provide an idea of the deficiency mentioned above in Experiment I.

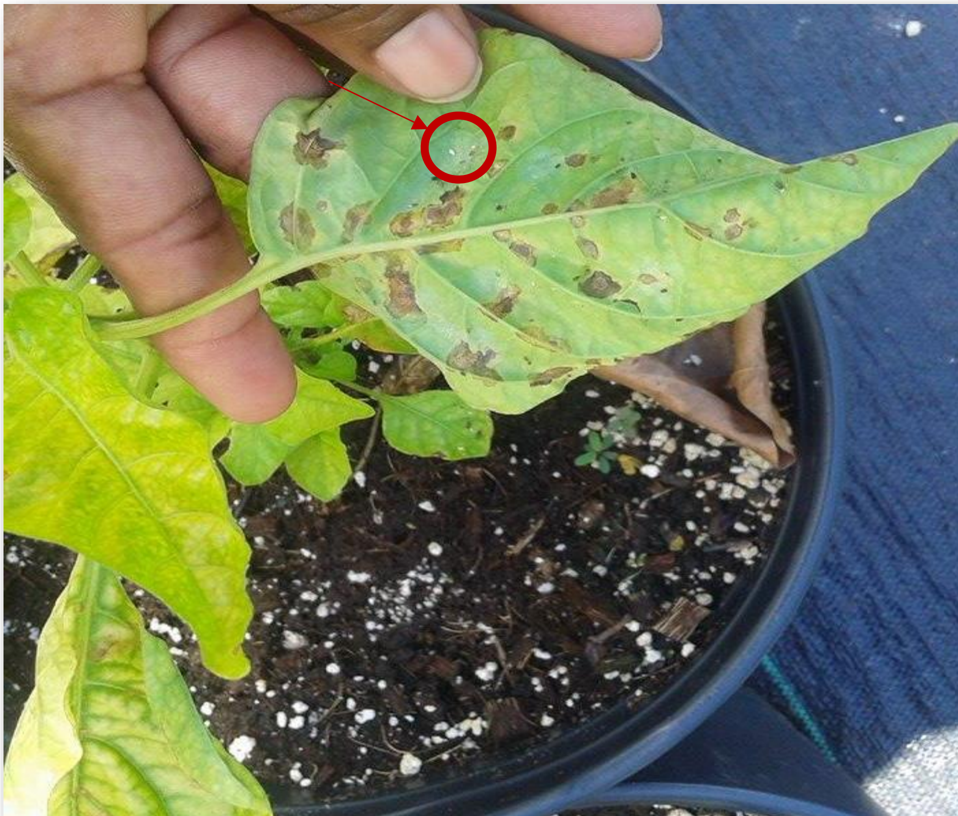

Figure 9. An example of foliar disease (dark, angular lesions) and whitefly infestation (red circle) observed in Experiment I June to October, 2017.

Figure 10. Typical symptoms of foliar leaf drop observed in Experiment I. Leaf drop was possibly due to a high infestation of whitefly and thrips. Foliar lesions are also visible in this photograph (June to October, 2017).

5.2 Experiment II

With the exception of 41 to 54 days after transplanting, no significant substrate x cultivar interactions were observed for plant height in Experiment II (Table 5). There were significant differences among substrates and among cultivars at each date that plant height was measured. In general, the CVs in Experiment II (Table 5) were very low, especially compared to Experiment I (Table 3).

At 26 days after transplanting plants in BX+Myco and HP+Myco+Fung were significantly taller (9.6 to 10.1 cm) than plants in the other three substrates (Figure 11). This trend continued through 82 days after transplanting, although at 82 days there was no significant difference between BX+Myco and BX. At 96 to 126 days after transplanting the height of plant in substrates BX+Myco, HP+Myco+Fung and BX did not differ and were significantly taller than plants in COCO. At 126 days after transplanting plant height reached 51.0 cm for BX+Myco.

Table 5. Sources of variation, degrees of freedom, probability values in F-test and coefficient of variation (CV) for plant height in four cultivars of *Capsicum chinense* grown in five planting substrates in Experiment II (December 2017 to May 2018).

		Days after transplanting						
Sources of variation	Degrees of freedom	26	41	54	68	82	96	126
Planting substrate (S)	4	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0003
Cultivar (C)	3	0.0011	0.0224	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
S x C	12	0.1160	0.0001	0.0143	0.9736	0.6671	0.7818	0.9214
CV (%)		12.6	17.4	16.7	15.1	13.4	13.5	13.4

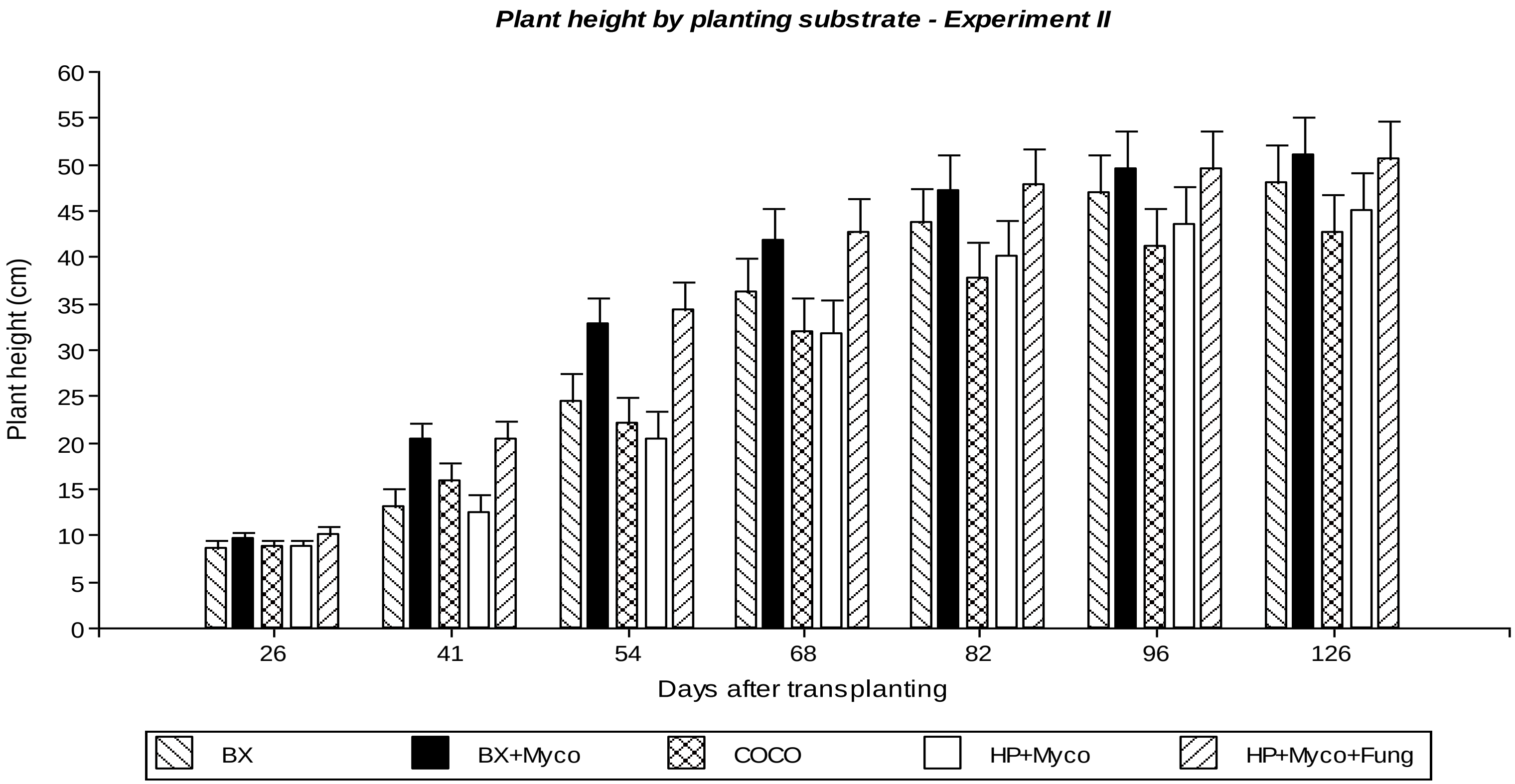

Figure 11. Mean plant height of *Capsicum chinense* in five planting substrates in PRO-MIX®BX (BX), PRO-MIX®BX + Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco) and PRO-MIX®High porosity + Mycorrhizae+Bio fungicide (HP+Myco+Fung). The mean of each substrates was averaged over four different cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

At 26 days after transplanting, no significant differences were observed in plant height for the three shortest cultivars, ‘Carnaval’ (8.8 cm), ‘Bonanza’(9.0 cm) and ‘Amanecer’ (9.2 cm), and the tallest cultivar was ‘Pasión’ (10.0 cm) (Figure 12). At 41 days after transplanting, the same trend continued with no significant differences observed in plant height for three of the cultivars, ‘Carnaval’(15.6 cm), ‘Amanecer’(16.0 cm), and ‘Bonanza’(16.1 cm), and ‘Pasión’(18.0 cm) being significantly taller. From 54 to 126 days after trasplanting ‘Amanecer’ and ‘pasíon’were generally the tallest cultivars while ‘Bonanza’ was intermediate in height and ‘Carnaval’was the shortest cultivar. At 126 days after transplanting ‘Amanecer’ measured 53.7 cm and ‘Pasión’ measured 51.6 cm in height.

There were significant differences between planting substrates and between cultivars for flowering time, total number of fruits per plant, total fruits weight and average fruit weight (Table 6). No significant substrate x cultivar interactions were observed. The coefficient of variation (C V) of total fruit weight was higher compare to the total number of fruits and average fruit weight indicating there was more variability in total fruit weight than total number of fruit per plant and average fruit weight. The coefficient of variation (CV) of flowering time was considerably lower than for total number of fruit per plant, total fruit weight per plant and average fruit weight indicating there was less variability associated with flowering time than for the other variables.

Plants in HP+Myco+Fung and BX+Myco were the earliest to flower at 45.6 and 50.3 days after transplanting, respectively (Figure 13). BX (56.8 days after transplanting) and HP+Myco (57.9 days after transplanting) were intermediate in flowering time. Plants in COCO were the latest to flower (67.2 days after transplanting).

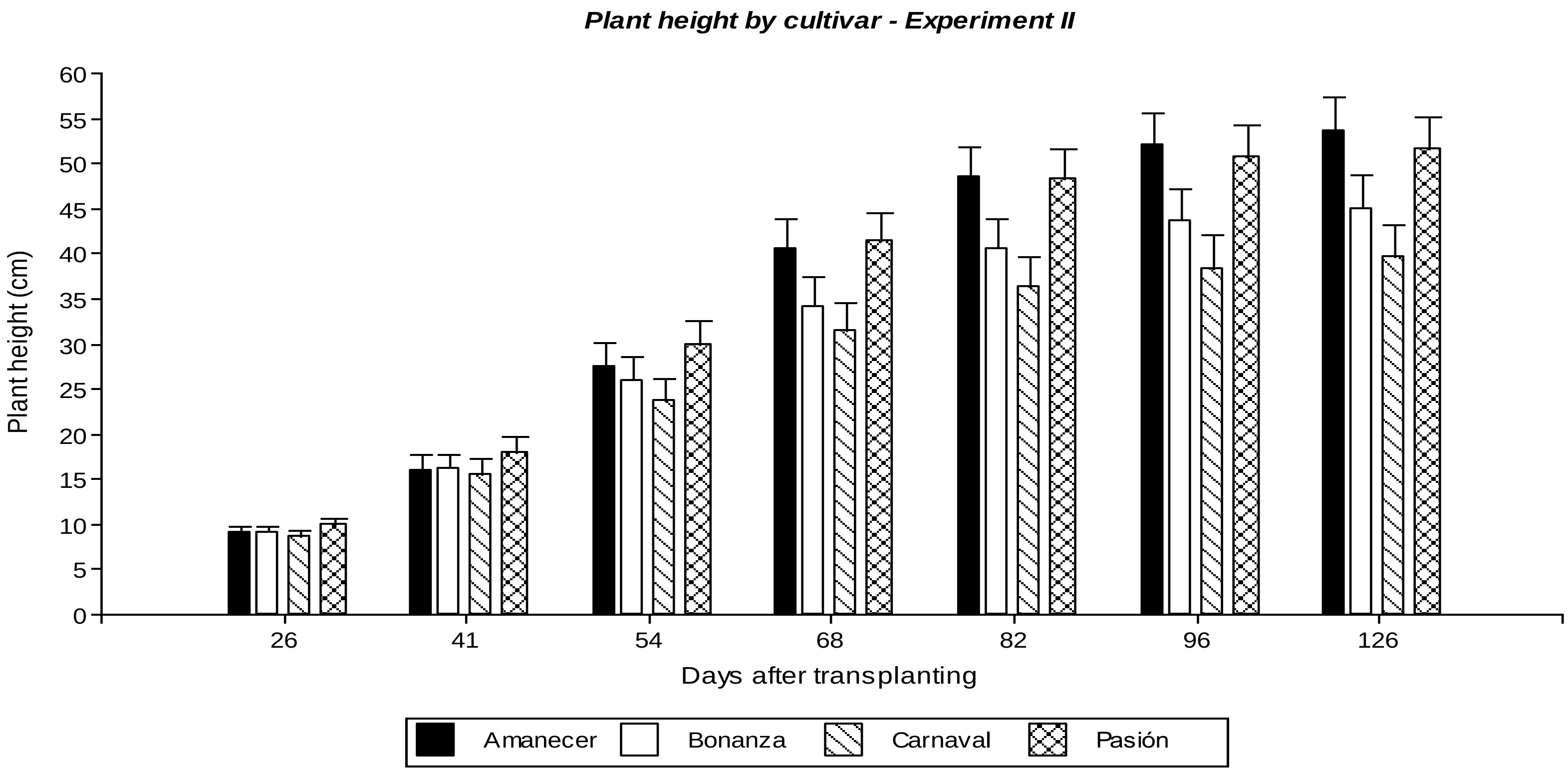

Figure 12. Mean plant height of four cultivars (‘Amanecer’, ‘Bonanza’, ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar is averaged in different over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

Table 6. Sources of variation, degrees of freedom, (F- test) probability values and coefficient of variation (CV) for flowering time, total number of fruit, total fruit weight and average fruit weight in four cultivars of *Capsicum chinense* grown in five planting substrates in Experiment II (December 2017 to May 2018)

		Probability (F-test)			
Sources of variation	Degrees of freedom	Flowering time	Total number of fruit per plant	Total fruit weight per plant	Average fruit weight
Planting substrate (S)	4	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar (C)	3	0.0298	<0.0001	<0.0001	<0.0001
S x C	12	0.5958	0.4438	0.1384	0.3413
CV (%)		13.55	37.68	76.50	38.39

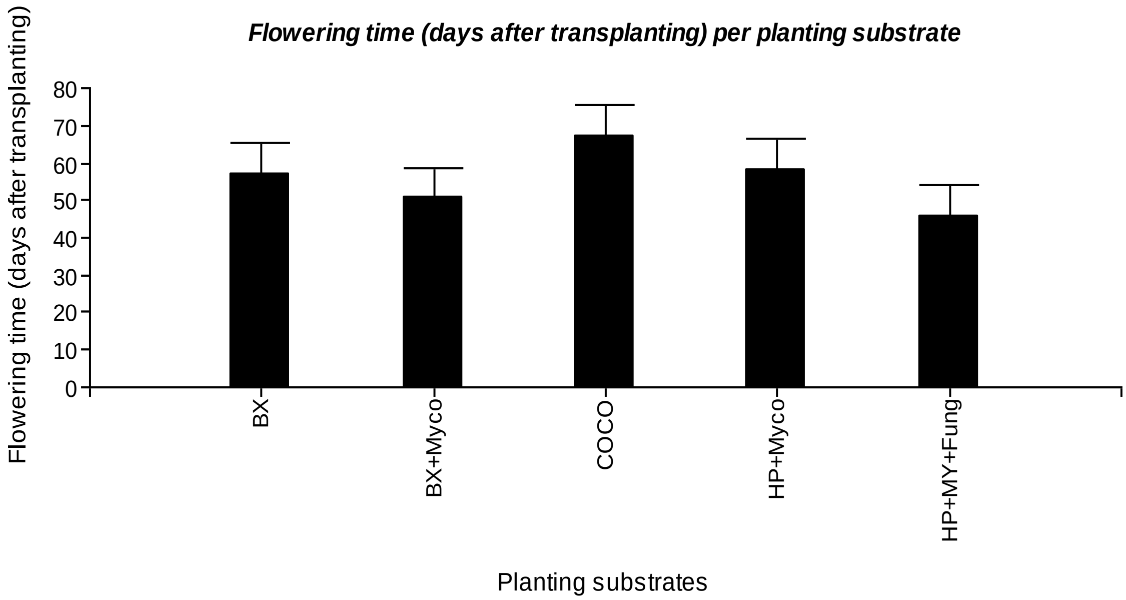

Figure 13. Mean flowering time (days after transplanting) of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco) and PRO-MIX®High porosity+Mycorrhizae+Biofungicide (HP+Myco+Fung). The mean of each planting substrate was averaged over four different cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

'Carnaval' and 'Bonanza' were the cultivars with the earliest time to flower at 51.4 days and 51.6 days after transplanting, respectively (Figure 14). 'Amanecer' (59.6 days after transplanting) and 'Pasión' (59.7 days after transplanting) were intermediate in flowering time.

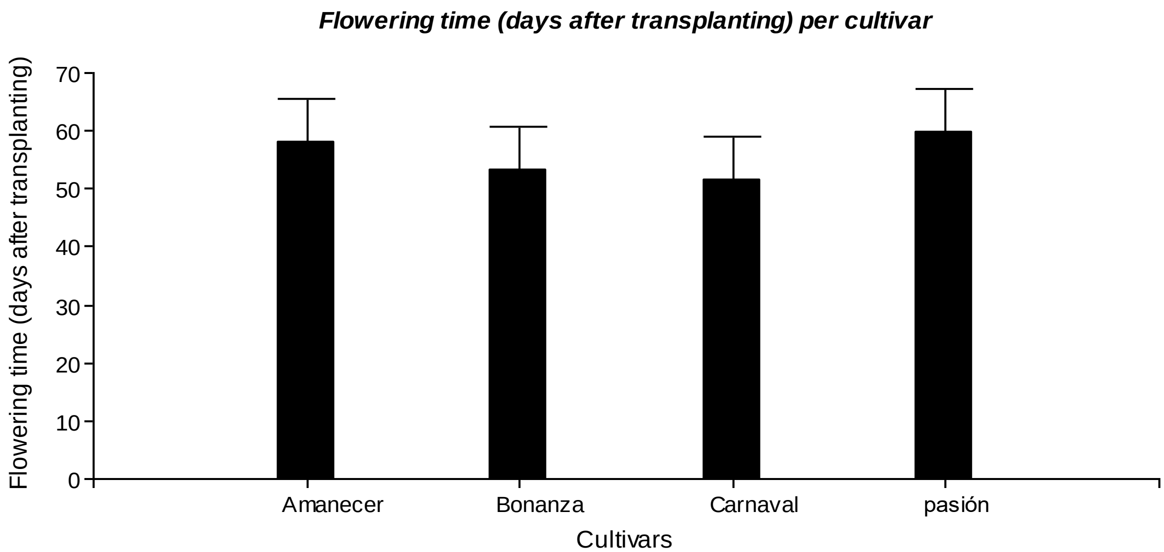

Figure 14. Mean flowering time (days after transplanting) of four cultivars (‘Amanecer’, Bonanza’, ‘Carnaval’, and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

Plants in HP+Mycorrhizae+Fung, BX+Myco and BX produced similar number of fruit per plant (81.5 to 71.8) (Figure 15). Plants in these substrates produced about nearly twice as many fruit as plants in COCO with only 41.7 fruit per plant.

‘Amanecer’ was the cultivar with the highest total number of fruit per plant (92.3) followed by ‘Pasión (72.5 fruit) (Figure 16). These cultivars produced about one and half to twice as many fruit as ‘Bonanza’ with 50.6 fruit per plant and ‘Carnaval’ with 44.0 fruit per plant. There was no significant difference in the number of fruit per plant for ‘Bonanza’ and ‘Carnaval’.

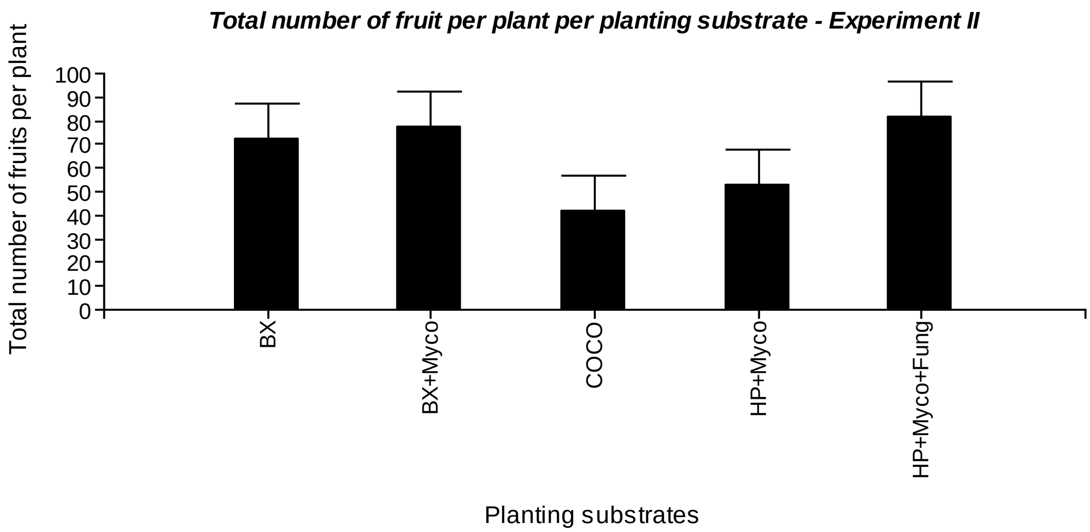

Figure 15. Mean total number of fruit per plant of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity + Mycorrhizae (HP+Myco), PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). The mean total number of fruit per plant was averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

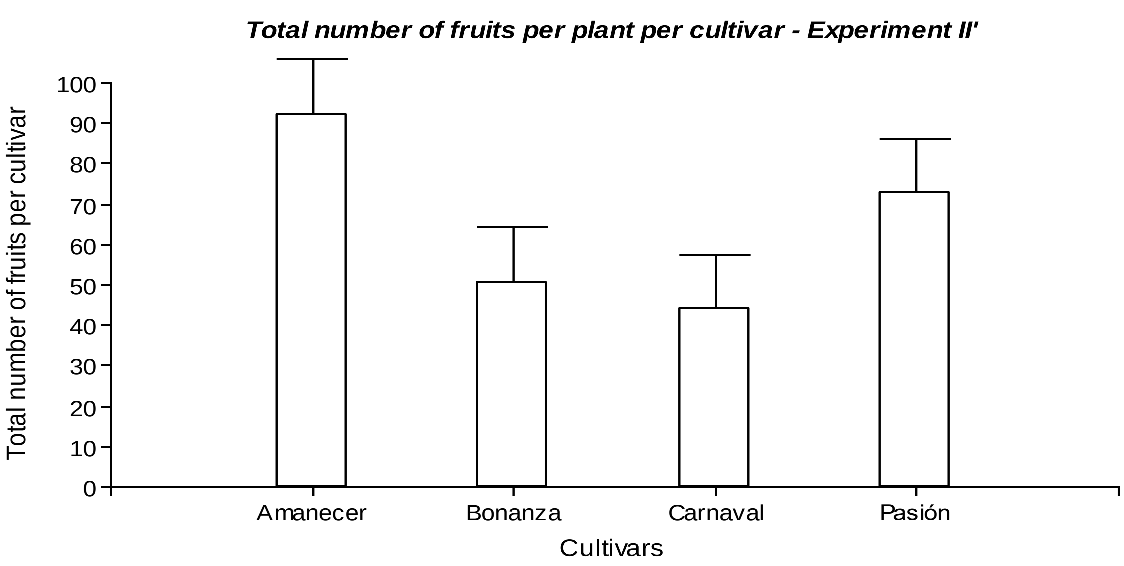

Figure 16. Mean total number of fruit per plant of four cultivars ('Amanecer', 'Bonanza', 'Carnaval' and 'Pasión') of *Capsicum chinense*. The mean of each cultivar was averaged over five different planting substrates. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

Total fruit weight per plant did not vary among the substrates HP+Myco+Fung, BX+Myco and BX (Figure 17). Plants in these substrates yielded from 875.1 to 933.5 g of fruit per plant. HP+Myco and COCO were the substrates producing plants with the lowest total fruit weight (633.0 and 470.4 g, respectively). There were no significant difference between HP+Myco and COCO.

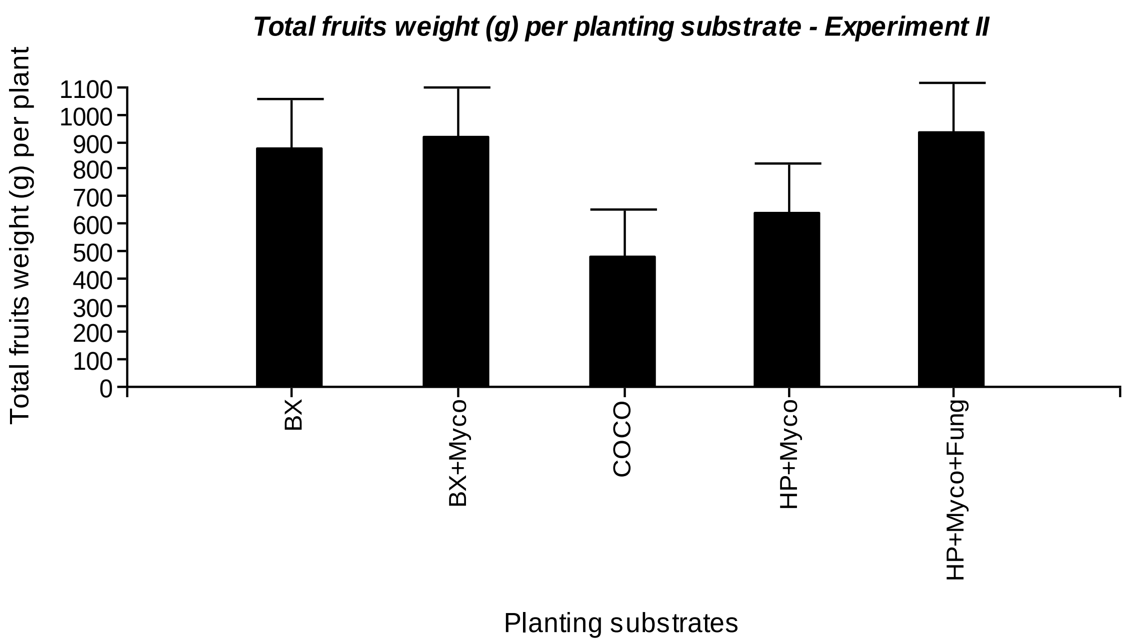

Figure 17. Mean total fruit weight per plant of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX + Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco) and PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). The mean total fruit weight per plant is averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

'Amanecer' was the cultivar with the highest total fruit weight per plant (1050.0 g) (Figure 18). There were no significant differences in total fruit weight per plant among the other three cultivars. Their yields range from 669.4 g per plant for 'Bonanza' to 592.0 g per plant for 'Pasión'.

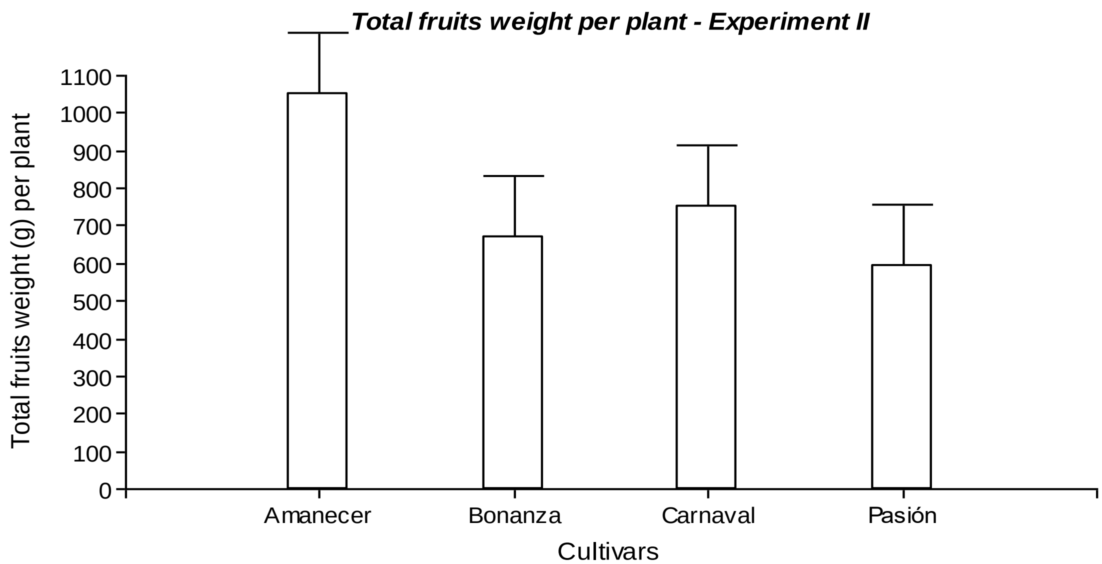

Figure 18. Mean total fruit weight per plant (g) of four cultivars (‘Amanecer’, ‘Bonanza’, ‘Carnaval’ and ‘Pasión’) of *Capsicum chinense*. The mean of each cultivar was average over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

BX+Myco and BX were the substrates with the highest average fruit weight (10.0 and 9.9 g). (Figure 19). There was no significant difference between HP+Myco+Fung and HP+Myco (8.9 and 8.1 g respectively), the substrates that produced the next highest average fruit weight. COCO was the substrate with the lowest average fruit weight (6.3 g).

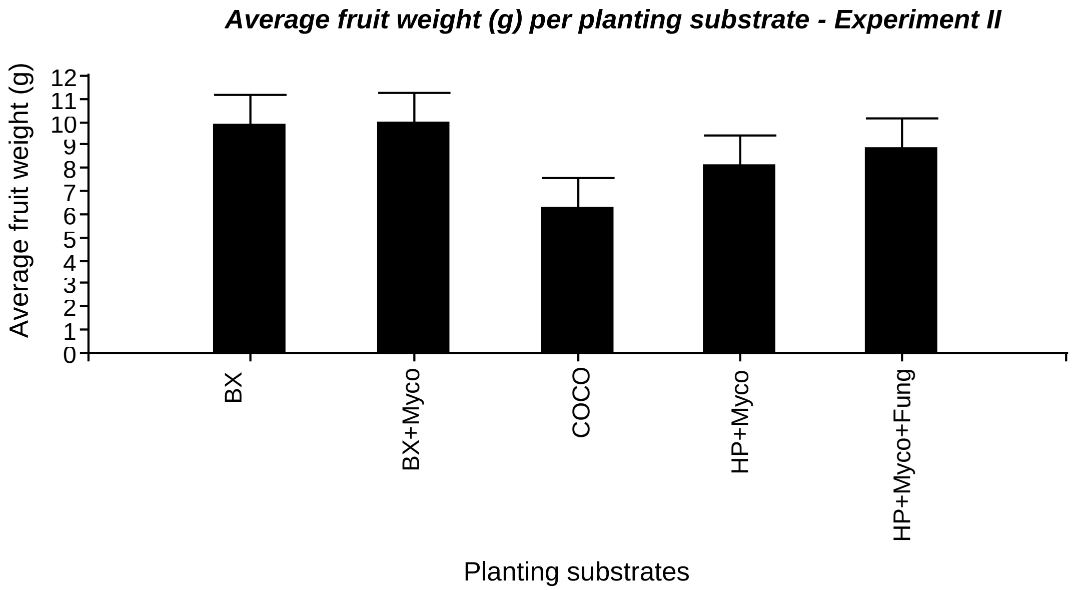

Figure 19. Average fruit weight of five planting substrates PRO-MIX®BX (BX), PRO-MIX®BX+ Mycorrhizae (BX+Myco), Coconut fiber (COCO), PRO-MIX®High porosity+Mycorrhizae (HP+Myco), PRO-MIX®High porosity+Mycorrhizae+Bio fungicide (HP+Myco+Fung). The average fruit weight of each substrate was averaged over four cultivars. Lines = Fisher's Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

'Carnaval' was the cultivar with the highest average fruit weight (11.5 g) (Figure 20). There was no significant difference between 'Amanecer' and 'Bonanza' (8.5 and 9.0 g respectively), the cultivars that produced the next heaviest average fruit weight. 'Pasión' was the cultivar with the lowest average fruit weight (6.0 g).

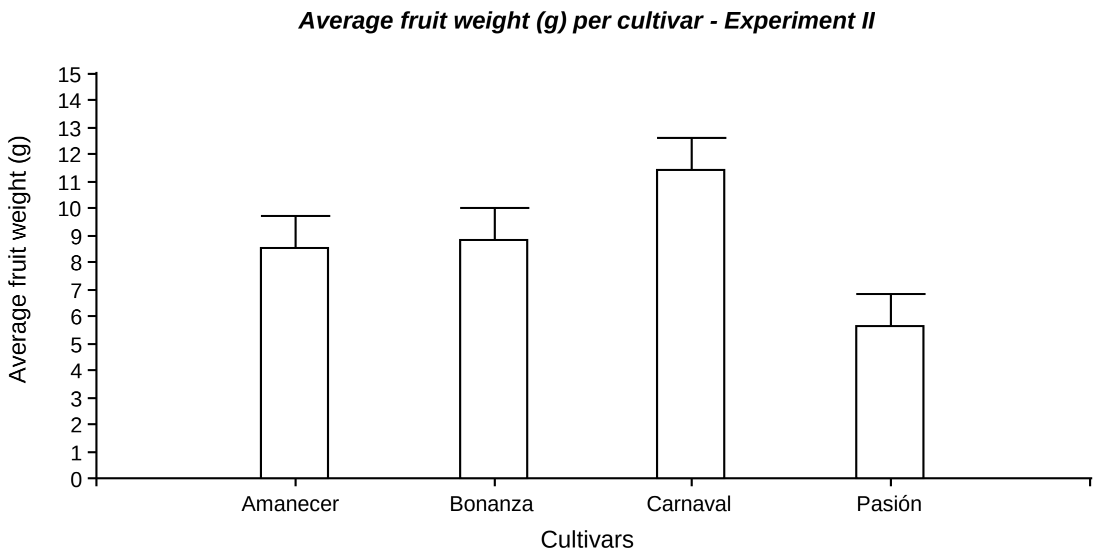

Figure 20. Average fruit weight of four cultivars of (‘Amanecer’, ‘Bonanza’ ‘Carnaval’ ‘Pasión’) of *Capsicum chinense*. Average fruit weight of each cultivar was averaged over five different planting substrates. Lines = Fisher’s Least Significant Difference at the 0.05 probability level. (Experiment II December 2017 to May 2018)

For many reasons including different planting sites, experience gained from the first experiment, and better care during the production steps, less nutrient deficiency was shown in experiment II (Figure 21). Therefore, big differences appeared between Experiment I and Experiment II among all the parameters.

Figure 21. General view of plants in the three blocks of Experiment II at 61 days after transplanting.

In Experiment II, differences were observed between roots of plants growing in different planting substrates. COCO and HP+Myco had almost the same size of roots and they grow deeper than plants of other substrates (Figure 22 and 23). In BX and BX+Myco the roots developed very well and had a good root mass compared to COCO and HP+Myco (Figure 24 and 25). In HP+Myco+Fung the roots developed very well and grew very deep (Figure 26).

Figure 22. Roots of cultivar Bonanza planted in PRO-MIX® High Porosity +Mycorrhizae.

Figure 23. Roots of cultivar Carnaval planted in coconut fiber.

Figure 24. Roots of Bonanza planted in PRO-MIX® BX.

Figure 25. Roots of cultivar Carnaval planted in PRO-MIX® BX + Mycorrhizae.

Figure 26. Roots of cultivar Amanecer planted in PRO-MIX® High Porosity + Mycorrhizae + Biofungicide.

6. Discussion

In Experiment I many plants were lost due to a variety of reasons. Whitefly and thrips infestation were observed very early on in the transplanted seedlings. Later, dark, angular foliar lesions were observed on many plants (Figure 9). A large number of plants exhibited severe leaf drop (Figure 10). There was a loss of almost 30% of plants before full maturity was reached. In contrast, growing conditions appeared to be ideal in Experiment II and almost all plants reached maturity. In general, plants in Experiment II showed few or none of the symptoms seen in Experiment I. An additional problem in Experiment I may have been that plants did not have enough sun during the late afternoon. The Experimental site was near a large tree that shaded the experiment in the afternoon. However, in Experiment II plants had full sun.

There were differences in Experiment I and II in terms of substrates that gave the best results. BX was the substrate that had the best results on plant height, total number of fruit per plant, total fruit weight per plant and average fruit weight in Experiment I. These results disagree with Aponte López. (2018) who indicated that plants grown in BX+Myco developed more than those in BX and only plants grown in BX+Myco produced fruits. BX, BX+Myco and HP+Myco+Fung were the substrates with the best results for all parameters in Experiment II. The reason for that was the planting weather. BX has high water holding capacity. In Experiment I the average temperature was different (86ºF) than the average temperature in Experiment II (76.5ºF).

Both Experiments I and II presented similar results as to the poorest performing substrates. COCO and HP+Myco were the poorest substrates with similar results for plant height, total number of fruit per plant and total fruit weight in both Experiments. These results agreed with Mazahreh et al. (2015) who showed that cucumbers grown in COCO had poorer production than cucumbers grown in a mix of COCO and peat moss. There were differences in Experiment I and II in average fruit weight. COCO and HP+Myco had similar results for average fruit weight in Experiment I, while in Experiment II only COCO had the worse result for average fruit weight. Generally COCO and HP+Myco were the poorest substrates in both experiments. It may be caused by overwatering because HP+Myco requires less frequent watering than other growing media and provides long-term ease of rewetting (Parent, 2018).

Plants in HP+Myco performed poorly while plants in a similar high-porosity product, HP+Myco+Fung did well, especially in experiment II. This might be primarily from the positive effects of biofungicide. COCO is also a high porosity product that is similar to HP+Myco in terms of physical properties. It presented poor results and seems not to be a good substrate for planting. Considering the results of different substrates used by this study, the focal point is put on BX as the substrate that seems the best for sweet chili pepper in Puerto Rico.

There were differences in Experiment I and II in terms of the cultivar that gave the best results. 'Bonanza' was the cultivar with the best results for plant height, total number of fruit per plant, total fruit weight, and average fruit weight in Experiment I, while 'Amanecer' was the cultivar which had the best results for all parameters except the average fruit size. Although 'Amanecer' had the highest number of fruit in Experiment II, it did not have the highest average fruit weight.

In contrast, both Experiments I and II presented similar results as to the poorest performing cultivars. All the cultivars presented similar results for all parameters except 'Bonanza' in Experiment I, while in Experiment II 'Carnaval' was the poorest cultivar for plant height and total number of fruit per plant, while 'Bonanza' had the lowest number of fruit per plant and total fruit weight per plant. However, ‘Bonanza’ was among the poorest cultivars in Experiment II, despite being the best in Experiment I.

This research recommends the use of BX as the substrate that produces the best results for several parameters of growth including total number of fruit per plant, total fruit weight per plant, flowering time and average fruit weight. Using BX would be more profitable due to its lower cost compared to other Pro-Mix products. The cultivars ‘Amanecer’ and ‘Bonanza’are recommended as the best sweet chili pepper cultivars for container production.

7. Recommended Future Research Studies

Future work should study all of the different substrates that are in use in Puerto Rico for soilless container production of not only *ají dulce*, but other vegetables as well. Effort should be made to look for local sources of substrates that are less expensive and better for the environment and pest control. Studies should be conducted to determine the effectiveness of the use of containers in the production of sweet chili pepper compared with production directly in the soil.

Broader surveys can be developed in the Department of Horticulture at the University of Puerto Rico at Mayagüez to determine the acceptance of soilless substrates evaluated in this study among local producers of sweet chili pepper.

Literature Cited

Aponte López, C.M. 2018. Response of *Capsicum chinense* to Mycorrhizae inoculation and local mycorrhizal diversity associated with the crop in Puerto Rico. A thesis research in Biology of University of Puerto Rico.

Bosland, P.W. 1996. Capsicum: Innovative uses of an ancient crop. pp. 479-487. In: Janick (ed.), Progress in new crops. ASHS press, Arlington, Virginia.

Burés, S. 1997. Manual de sustratos. I Curso de gestión de viveros forestales. Retrieved from: https://doi.org/http://www.juntadeandalucia.es/medioambiente/consolidado/publicacionesdigitales/80373 I Curso de gestion de viveros forestares/80-373/7 Manejo de sustratos.pdf

Barboza, G. E., and L. De Bem Bianchetti. 2005. Three Gaew species of *Capsicum* (Solanaceae) and a Key to the Wild Species from Brazil. Systematic Botany, 30: 863–871. https://doi.org/10.1600/0363644405775097905

Butt, S.J., N.A. Abbasi, and T. Mahmood. 2007. Role of various growing substrates on the yield and quality of greenhouse crops. Proc. International Symposium on Prospects of Horticultural Industry in Pakistan. Hort. Sci. Inst. P. 27–37.

Capinera, J. L. 2017. Pepper weevil, *Anthonomus eugenii* Cano and cuban pepper weevil, Faustinus cubae (Boheman). (Insecta : *Coleoptera : Curculionidae)*. Department of Entomology and Nematology, UF/IFAS Extension, pp. 1–6.

Castillo, C.R., L.S. Sotomayor, C.O. Ortiz, G.C. Leonelli, F.B. Borie, and R.H. Rubio. 2009. Effect of arbuscular mycorrhizal fungi on an ecology crop of chili peppers (*Capsicum annuum* L.). Chilean Journal of Agriculture Research. 69:79-87.

Charlo, H.C., S.F. De Oliveira, R. Castoldi, P.F.Vargas, L.T. Braz, and J.C. Barbosa. 2011. Growth analysis of sweet pepper cultivated in coconut fiber in a greenhouse. Horticultura Brasileira. 29:316–323.

Cloyd, R.A. 2016. Spot pests that negatively impact bell pepper. Department of Entomology at Kansas State University. Retrieved 9-April-2018

Cruz-Crespo, C., A. Can-Chulim, M. Sandoval-Villa, R. Bugarín-Montoya, A. Robles-Vermúdez, and P. Juárez-López. 2013. Sustratos en la horticultura. Revista Biociencias 2:17–26.

Department of Agriculture of Puerto Rico 2016. Ingreso bruto de la agricultura Puerto Rico. Divisíon de Estadísticas Agrícolas, Departamento de Agricultura, San Juan, Puerto Rico. Retrieved 7-October- 2018. http://www.estadisticas.gobierno.pr/iepr/LinkClick.aspx?filetiket=yTlplq4sUxE%3d&tabid=186

Di Rienzo J.A., F. Casanoves, M.G. Balzarini, L. Gonzalez, M. Tablada, and C.W. Robledo. InfoStat versión 2018. Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. URL http://www.infostat.com.ar

Eshbaugh, W.H. 1993. History and exploitation of a serendipitous new crop discovery. pp. 132-139. In J. Janick and J.E. Simon (eds.), new crops. Wiley, New York.

Estévez de Jensen, G., I.E. Badillo-Vargas, G. Frantz and H.C. Mellinger. 2017. First report of tomato chlorotic spot virus in the non-solanaceous weeds erect spiderling (*Boerhavia erecta*), Asian Spiderflower (*Cleome viscosa*), and sweet chili pepper (*Capsicum chinense*) in Puerto Rico, 18: 17–18.

Gabriel, M.Z., J. E. Altland, and J.S. Owen Jr. 2009. The effect of physical and hydraulic properties of peat moss and pumice on douglas-fir bark based soil-less substrates. HortScience, 44:874–878.

Gruda, N. 2009. Do soilless culture systems have an influence on product quality of vegetables ? Humboldt University of Berlin, Institute for Horticultural Sciences, 147: 141–147.

Jovicich, E., D.J. Cantliffe, N.L. Shaw, and S.A. Sargent. 2003. Production of greenhouse-grown peppers in Florida. University of Florida IFAS Extension, (HS979).

Kelley, W., G. Boyhan, and K. Harrison. 2009. Commercial pepper production handbook. Retrieved 21 February 2018. http://athenaeum.libs.uga.edu/handle/10724/12339/

Kloepper, J. W., C. Ryu, and S. Zhang. 2004. Induced systemic resistance and promotion of plant growth by Bacillus spp. American Phytopathological Society 94:1259–1266.

López-Puc, G., A. Canto-Flick, F. Barredo-Pool, P. Zapata-Castillo, M.D.C. Montalvo Peniche, F. Barahona-Pérez, and L. Iglesias-Andreu, 2006. Direct somatic embryogenesis: A highly efficient protocol for in vitro regeneration of habanero pepper (*Capsicum chinense* Jacq). HortScience. 41:1645–1650.

Lopez, J.C. 2018. How substrate structure influences air porosity. Premier Tech Horticulture, Pro-Mix training Center. Retrieved 20 October 2018. <https://www.pthorticulture.com/en/training-center/how-structure-influences-air-porosity/>

Lowell, L.B., K. S. Green, G.L. Hartman, and J.M. Poulos. 1991. Pepper diseases (A field guide). Asian Vegetable Research and Development Center, AVRDC. pp. 92-97.

Mangan, F., B. Zoraia and M. Maria. 2008. Pepper varieties for your markets: From bells to habaneros. UMASS Extension. Retrieved from fmangan@umext.umass.edu%0APeppers. 11 October, 2017.

Moscone, E.A., M.A. Scaldaferro, M.G. Nicolãs, M. Cecchini, Y. Sanchez Garcia, R. Jarret, J.R. Daviña, D.A. Ducasse, G. E. B. and F. E. 2007. The evolution of chili peppers (*Capsicum - Solanaceae*): A cytogenetic perspective, VIth International solanaceae Conference. Acta Hort. 745: 1–33.

Mazahreh, N., A. Nejatian, and M. Mousa. 2015. Effect of different growing Medias on cucumber production and weter productivityin soilless culture under UAE conditions. Merit Journal of Agricultural Science and soil Sciences. 3: 131-138.

Moyer, C., and N.A. Peres. 2008. Evaluation of biofungicides for control of powdery mildew of gerbera daisy. Proc. Fla. State Hort. Soc. 121:389–394.

Olympios, C. M. 1979. Overview of soilless culture: Advantages, constraints and perspectives for its use in Mediterranean countries. Department of Vegetable Production. Agricultural University of Athens 31: 307-324.

Parent, S. 2018. Pro-Mix pur mycorrhizae zeolite. Premier Tech Horticulture, Pro-Mix training Center. Retrieved 20 October 2018. <https://www.pthortoculture.com/en/training-center/pro-mix-pur-mycorrhizae-zeolite/>

Pereira, J.A.P., I.J.C. Vieira, M.S.M. Freitas, C.L. Prins, M.A. Martins, R. Rodrigues. 2015. Effects of arbuscular mycorrhizal fungi on *Capsicum* spp. The Journal of Agricultural Science 154:828-849.

Pickersgill, B. 2003. Encyclopedia of food sciences and nutrition. Peppers and chillies. 2: 4460 – 4467. Retrieved 22 October 2018.

Roldán, G.Q. 2015. Producción de chile dulce en invernadero bajo diferentes niveles de agotamiento en la humedad del sustrato. Agronomía Costarricense 39:25–36.

Ruiz-Sifre, G., and C. Flores-Ortega, 1995. Survey on fungal diseases affecting vegetable crops in Southern Puerto Rico. J. Agrie. Univ. P.R. 87: 155-160.

Sonneveld, C. 2004. Effects of salinity on substrate grown vegetables and ornamentals in greenhouse horticulture. Wageningen Univ. (Netherlands). P.1-149.

Taylor, N.J., S. Nemeth, and J. Chatfield. 2010. Diagnosing problems on indoor plants. HYG-3068-96. Retrieved 24 October 2018. http://ohio.osu.edu/hyj-fact/3000/3068.html.

Tzortzakis, N.G., and C.D. Economakis. 2008. Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation. Horticultural Science. 35: 83–89.

Valenzuela, O.R., C.S. Gallardo, M.S. Carponi, M.E. Aranguren, H.R. Tabares and M.C. Barrera. 2014. Manejo de las propiedades físicas en sustratos regionales para el cultivo de plantas en contenedores. Ciencia, Docencia y Tecnologia Suplemento 4:1–19.