Yield and Quality Performance of Eleven Open Pollinated and Three Hybrid Tomato Cultivars Grown Under Organic Management in Lajas Puerto Rico

by

Kevin Brady

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

MASTER OF SCIENCE
In
HORTICULTURE

UNIVERSITY OF PUERTO RICO
MAYAGUEZ CAMPUS
2011

Approved by:

Bryan Brunner, PhD President, Graduate Committee	Date
Sonia Martínez Garrastazú, MS Member, Graduate Committee	Date
J. Pablo Morales-Payán, PhD Member, Graduate Committee	Date
Hipolito O'Farrill Nieves, PhD Department Chair	Date
Cathy Mazak, PhD Representative of Graduate Studies	Date

ABSTRACT

Organic variety trials were conducted in 2010 and 2011 to evaluate 14 tomato (*Solanum lycopersicum L.*) cultivars at Lajas, Puerto Rico. Significant differences in marketable fruit yield were observed among cultivars in both years. In 2010, yields ranged from 72.1 t/ha for ‘Roma’ to 8.6 t/ha for ‘Marion’, with an overall mean of 36.4 t/ha. ‘Roma’, ‘Neptune’ (56.8 t/ha), and ‘BHN 444’ (56.2 t/ha) had the highest yields in 2010. In 2011, yields ranged from 46.1 t/ha for ‘Flora Dade’ to 8.7 t/ha for ‘Roma’, with an overall mean of 27.8 t/ha. ‘Flora Dade’, ‘BHN 444’ (43.5 t/ha), and ‘Celebrity’ (38.3 t/ha) had the highest yields in 2011. Open pollinated cultivars performed with more variability between the two seasons than the hybrid controls. This study indicates that tomato can be grown successfully in the tropics under an organic management system using either open pollinated cultivars or hybrids.

RESUMEN

Se llevaron a cabo pruebas de variedades en Lajas, Puerto Rico en 2010 y 2011 para evaluar 14 cultivares de tomate (*Solanum lycopersicum* L.) con manejo orgánico. Se observaron diferencias significativas entre cultivares para el rendimiento comercial de frutas para los dos años. En el 2010, el rango de rendimiento fue entre 72.1 t/ha para 'Roma' a 8.6 t/ha para 'Marion', con un promedio general de 36.4 t/ha. 'Roma', 'Neptune' (56.8 t/ha) y 'BHN 444' (56.2 t/ha) tuvieron los rendimientos más altos en el 2010. En el 2011, hubo un rango en el rendimiento de 46.1 t/ha para 'Flora Dade' a 8.7 t/ha para 'Roma, con un promedio general de 27.8 t/ha'. 'Flora Dade', 'BHN 444' (43.5 t/ha) y 'Celebrity' (38.3 t/ha) tuvieron los rendimientos más altos en el 2011. Los cultivares de polinización abierta presentaron mayor variabilidad entre años que los testigos híbridos. Este estudio indica que se puede cultivar el tomate exitosamente bajo un sistema de manejo orgánico en el trópico usando cultivares de polinización abierta o híbridos.

ACKNOWLEDGEMENTS

I would like to express my appreciation for my wife, Elke, and my daughter, Anna-Maria.

I would like to express my gratitude to my parents, Mike and Rosalie, for their support

I would also like to thank by advisor Bryan Brunner for the opportunity to work on this project and extend my appreciation for his leadership and research in organic agriculture in Puerto Rico.

In addition, I would like to thank members of my graduate committee, Sonia Martínez-Garrastazú and Dr. J. Pablo Morales-Payán for help in my research.

Furthermore, I would like to acknowledge the help and support of everyone at the University of Puerto Rico Agricultural Experiment Station in Lajas, especially Luisa Flores-López, Juan Toro-Santiago, and Alvin Morales

I would like to thank the Department of Crops and Agro-environmental Sciences at the University of Puerto Rico for allowing me to pursue a master’s degree in organic horticulture.

Sources of funding that made this research possible:

-USDA grant NRCS 69-F352-09-01 “Promoting organic agriculture in Puerto Rico through organic seed production and education”

-AES grant SP-440 “Evaluation of diverse tomato germplasm under organic management”

TABLE OF CONTENTS

TABLE LIST

FIGURE LIST

INTRODUCTION

Local organic vegetable production can be adopted as a strategy for improving food security and environmental protection in Puerto Rico. The island is highly dependent on conventionally produced imported foods. Presently, Puerto Rico imports an estimated 80 to 90% of its food (Govardhan, 2007; Ryan, 2011). Also, imported vegetables are typically transported thousands of miles before reaching consumers in Puerto Rico, which greatly increases the energy requirement and carbon footprint for these perishable products (Hill, 2008). Most of the vegetables sold in Puerto Rico are produced in California, and are grown in highly mechanized monocultures with synthetic fertilizers and agrochemicals (Mendum and Glenna, 2010). In Puerto Rico, much of the prime farmland on the south coast is not used to support the local food system. Instead, large transnational corporate seed companies, like Monsanto, are producing seeds for international sales. Local organic food systems can help to reduce our dependence on imported foods. One of the primary steps toward food security in Puerto Rico is to identify and/or develop vegetable varieties that are adapted to organic management systems under tropical conditions. Choosing the right crops and varieties for local agro-ecosystems can significantly minimize crop failure and increase agricultural success (Colley and Myers, 2007).

Tomato is the most popular and widely grown vegetable in the world (Asgedom et al., 2011). In economic importance it is second only to potato (Tomato world production statistics, 2005). Tomatoes, along with potatoes, lettuce, and onions are the most accepted and consumed fresh produce in America (O’Connell, 2008). Consumers in America are 3 to 4 times more likely to buy organic tomatoes than any other produce (O’Connell, 2008). Tomatoes can be eaten raw or cooked and are a common ingredient in Puerto Rican cuisine.

Conventional tomato production relies heavily on non-renewable inputs such as petrochemicals. Florida Tomato Committee (FTC) manager Reggie Brown said that, “Everything we do on the farm requires energy in the form of nitrogen fertilizer, petrochemicals, or plastic mulches" (Tomato Magazine, 2005). Conventional tomato farms are highly dependent on inexpensive petrochemicals to remain competitive (Tomato Magazine, 2005).

Conventional produce is commonly transported thousands of miles from farm to consumer (Hill, 2008). A tomato grown in California and shipped to Puerto Rico must travel over three thousand miles before reaching a consumer. Of all the energy consumed in conventional food systems, 20% goes into production, and 80% is associated with processing, refrigeration, and transport (Hill, 2008). In Puerto Rico, tomatoes produced for export are shipped in refrigerated containers to Jacksonville, Florida where they are then trucked throughout the U.S. (Ge, 2006). Transporting food over thousands of miles may quickly become prohibitive if gasoline prices rise significantly in the future and/or legislation limiting greenhouse emissions is enacted.

In Puerto Rico, nearly all the tomatoes produced are grown on the south coast. This region, which was once dominated by intensive sugar cane cultivation, is now dominated by intensive vegetable production and international seed development. These industrial farms, especially seed companies, apply heavy applications of fertilizers and agrochemicals for disease and insect control (Pérez-Alegría et al., 1997). The land use change from sugar cane to intensive vegetable/seed production has contributed to surface and groundwater contamination in the coastal plain (Pérez-Alegría et al., 1997).

The largest tomato farm on the south coast of Puerto Rico is structured for export operations. Gargiulo Inc is a multinational corporate tomato farm designed to supply tomatoes to the U.S. in the winter months during peak demand (Ge, 2006). Prices peak in the U.S. for fresh market tomatoes in January and February when it is too cold to grow tomatoes in Florida (Ge, 2006). If gasoline prices rise to a point where it is not economically viable to produce and ship tomatoes to the U.S., these companies are likely to leave Puerto Rico.

A logical way to provide food security to Puerto Rico is to develop a local food system. Local food systems would require the regeneration of our productive farmland

and a shift away from urban development, and food importation and retailing (Guptill, 2004). Local food systems could reduce Puerto Rico's dependence on imported foods, with their inherent instability, contribute to local economies, and provide greater connectedness and trust between consumers and producers (Pretty, 2001). Local organic food systems can also help to reduce Puerto Rico's carbon footprint by decreasing the distance food travels.

Organic agriculture could provide long-term sustainability to a local food system. Organic production systems typically have less reliance on external and non-renewable farm inputs than conventional agricultural models. Organic materials, generated on the farm or locally sourced, are used to raise soil fertility levels. Soil improvement, or "feeding the soil to feed the plants," is a basic organic management strategy. Higher fertility levels from organic matter additions support a greater diversity of organisms both above and below the ground. This functional biodiversity enhances system stability through ecosystem services like biological pest control and nutrient cycling (Lammerts van Bueren et al., 2002).

Organic agriculture is fundamentally different than conventional agriculture (Lammerts van Bueren et al., 2002). The goal of organic farming is to encourage functional agro-biodiversity through organic matter additions, an assortment of species and mixed varieties. Organic systems are complex ecological systems, which promote the long-term heath of the farm ecosystem (Lammerts van Bueren, 2002). Conventional agricultural systems are industrial models that are primarily concerned with maximizing profits (Mendum and Glenna, 2010). Industrial agricultural systems have very specific mechanized management practices, which make monocultures more efficient than mixed plantings (Mendum and Glenna, 2010). Gepts (2006) claims that high input mass production agricultural systems are "the single most important threat to biodiversity". Agricultural systems with high levels of biodiversity have more diverse genetic resources to adapt to environmental change.

Most of the commercially available vegetable cultivars have been developed and adapted to conventional agricultural systems. These systems are characterized by the use of large quantities of chemical inputs, mechanized management practices, the dependence on a handful of varieties for its major crops, and increasingly on genetic engineering (Mendum and Glenna, 2010). Research shows that cultivars do not perform equally in conventional and organic productions systems (Murphy et al., 2007). Cultivars developed using conventional management practices may not have the optimal genetics for organic systems (Lammerts van Bueren, 2002). The organic sector needs crop cultivars developed and propagated under organic management.

The use of open pollinated (OP) cultivars plays an integral role in local organic seed systems, because seed can be saved and improved by farmers. Due to their inherent genetic elasticity, open pollinated cultivars can be adapted to local conditions (Colley and Dillon, 2004).

The objectives of the research presented in this paper were to: 1) evaluate the yield and quality performance of eleven open pollinated tomato cultivars and three hybrids under an organic management system; and 2) select superior performing tomato cultivars for local organic tomato production and organic seed production.

LITERATURE REVIEW

Tomato (*Solanum lycopersicum* L.) is the most economically important vegetable grown in Puerto Rico. During the 2008-2009 season, agricultural gross income for tomatoes was 24.4 million dollars (Departamento de Agricultura de Puerto Rico, 2010). The second leading crop was pumpkin at 5.7 million dollars (Puerto Rico Department of Agriculture, 2010). Virtually all of the tomatoes produced in Puerto Rico are grown conventionally on the south coast during the dry season. The largest producer on the island is Gargiulo Inc. in Santa Isabel, which produces 37.5 million pounds of tomatoes on 600 acres each year (Vetiver Solutions Blog, 2010). Gargiulo Inc. is a vertically integrated company, meaning they are involved in all aspects of the tomato supply chain. This includes seed research, production, packing, distribution, marketing, and sales of their tomatoes (Securities and Exchange Commission, 1996). Tomatoes are harvested in Puerto Rico from January until the end of March for export to the United States (Ge, 2006). Peak demand for exported Puerto Rican tomatoes is in January and February when production is low in Florida (Ge, 2006). Only green tomatoes are exported to the U.S.; any tomatoes with color change are sold in the local market (Ge, 2006). During the winter season, Puerto Rico imports 40% of its tomatoes, while the rest of the year 90% are imported (Almodóvar and Alamo, 1999).

Gargiulo Inc. has tomato operations in Florida, California, Mexico, and Puerto Rico. These diverse farm locations allow them to deliver fresh tomatoes to supermarkets in the United States all year round. Furthermore, since they control all aspects in the tomato supply chain they are able to maximize profits and maintain high quality standards (Ge, 2006).

Small farmers in Puerto Rico cannot expect to compete with large vertically integrated transnational corporate farms in the tomato export market. Instead, local small-scale farmers can participate in niche markets, like farmers markets, organic markets, restaurants and CSAs (Community Supported Agriculture). By selling directly to consumers, farmers can charge retail prices for their produce (Bachmann, 2008). A farmers market is a great place to learn what consumer's value, and tailor a production system to directly meet consumer needs (Bachmann, 2008). Organic produce is particularly in high demand; in fact, producers at the Rincon Farmers Market are required to sell only organic produce. In general, consumers at Rincon's Farmers Market are looking for great tasting, attractive produce which is free from pesticide residue. Also, most consumers are well aware that they are supporting local economies and families.

Fresh market tomato production is filled with many challenges because it is a high management crop (Palada and Davis, 2001). Tomatoes require intensive hand labor input for operations such as staking, fertilization, mulching, cultivation, pruning, tying, training, spraying, and harvest. Tomatoes are also highly vulnerable to insect and disease damage. Without a well-timed insect and disease management program in the tropics, yields can be greatly compromised. Fresh market tomatoes are also highly perishable, which requires efficient handling and marketing (Diver et al., 1999). Farm managers must also pay close attention to the weather, especially the seasonal variation in temperature and rain. High temperatures can inhibit fruit set (Peet and Bartholemew, 1996), whereas heavy rains can deteriorate fruit quality (Diver et al., 1999). Successful tomato production requires intensive manual labor and sound management practices.

One of the most important decisions a tomato farmer can make is variety selection (Fornaris, 2007). The use of well-adapted cultivars allows for stable yields under tough growing conditions, which can significantly increase agricultural success (Colley and Myers, 2007). Variety trials are conducted to identify superior performing cultivars. Varieties often perform differently in different environments due to genotype-environment interactions (Lammerts van Bueren et al., 1999). Typically, variety trials are conducted at different locations, in different seasons, or in different years, due to the fact that soil type, climate, and the fluctuation in disease and insect pressure will all affect a cultivar's overall performance.

Large seed companies trial their varieties under conventionally managed agricultural systems (Lammerts van Bueren, 2003). These conventional systems do not have the same selective pressures as organic systems and therefore do not promote the development of optimum genetics for organic production. Also, their use of toxic agrochemicals does not meet the ethical and ecological guidelines of organic farming (Lammerts van Bueren, 2002). It is important to conduct organic variety trials to determine which varieties perform best under organic management. For example, cultivars with traits like deep, extensive root systems or the ability to interact with beneficial soil microorganisms may perform better in an organic system versus a conventional system (Lammerts van Bueren et al., 2002).

Organic farmers require greater access to certified organic seed stock (Adam, 2005). Presently, a USDA National Organic Program (NOP) rule states that organic growers must use organic seed, when available (Federal Register, 2000). In Washington State only 1% of the organic acreage was sown with organic seed in 2003 (Colley and Dillon, 2004). The reasons for the lack of organic seed use include: 1) The lack of research and development for organic seed production and breeding, 2) Higher priced and lower quality organic seed, and 3) The lack of any timeline requiring full use of organic seed by the NOP (Colley and Dillon, 2004). Organic variety trials allow suitable varieties to be identified for a specific region and then propagated for organic seed.

In the short term, researchers and farmers need to work together to assemble superior performing open-pollinated cultivars. Saving seeds and adaptive selection has been an integral part of farming since the beginning of agriculture. Yet today, most of the large seed companies have eliminated much of their open-pollinated stock in favor of hybrid and genetically modified seed (Dillon and Hubbard, 2011). Some hybrids and all genetically modified plants have patent laws prohibiting their reproduction. Unlike hybrid and genetically modified seed, open pollinated seed can be collected, replanted and grown true to type. The farmer can participate in the improvement of open pollinated cultivars by selecting plants with the best characteristics season after season. In the long term, locally adapted germplasm can be used for bioregional organic plant-breeding programs.

The organic farming movement needs new varieties that are bred under low input organic conditions (Lammerts van Bueren et al., 2010). Over 95% of the varieties used in organic agriculture were bred under conventional high input conditions (Lammerts van Bueren et al., 2010). These varieties often lack adaptive traits that are important under organic production systems (Lammerts van Bueren et al., 2010). For example, organic breeding programs may select crop genotypes that are able to increase nutrient use efficiency, form symbiotic relationships with soil microbes, and be tolerant to disease, insects, and abiotic stresses (Lammerts van Bueren et al., 2010). These ideal variety characteristics or crop ideotypes can provide the genetic materials for the development of improved varieties (Lammerts van Bueren, 2003). Since it can take 10 years or more to develop a new crop variety, crosses between the outstanding parental varieties need to be made early in the breeding process (Lammerts van Bueren et al., 2010), but those parental genotypes first need to be identified.

Researchers at the University of Puerto Rico have conducted tomato variety trials at agricultural experiment stations (AESs) throughout the island. The results have been summarized in several reports (Wessel-Beaver et al., 1990; Fornaris et al., 1991; Colberg-Rivera et al., 1996; Fornaris et al., 2009). These variety trials demonstrate that location, season, and year influence a cultivar’s overall performance. Yet, all of these variety trials were managed under a conventional system using high inputs and primarily hybrid varieties. There is a need for information on tomato cultivar performance under organic management in the tropics.

MATERIALS AND METHODS

Experimental site

The tomato organic variety trials were conducted at the Lajas Agricultural Experiment Station in southwestern Puerto Rico (lat. 18° 01’ N, long. 67° 04’ W, elevation 27 meters) (Fig. A-1 & A-2). The soil series is Fraternidad clay that is very deep, moderately well drained, very slowly permeable and weathered from volcanic rock and limestone (National Cooperative Soil Survey USA, 2006). Monthly climatic data has been compiled in Table A-1. During the winter/spring season, average precipitation ranges from about 5 cm in January to over 10 cm in May (Table B-1). Soil tests on site revealed very high levels of potassium, magnesium, calcium, and copper, with very low levels of phosphorous and zinc. Soil pH was 8.2 (Table B-2).

Experimental design

Fourteen cultivars were evaluated during the 2010 and 2011 winter/spring season (Fig. A-3). Eleven cultivars were open pollinated and three cultivars were hybrid controls. Half of the varieties had an indeterminate growth habit and half had a determinate plant type. Varieties were chosen for their suitability for fresh market organic production. The criteria for variety selection were as follows (Table B-3): 1) cultivars were open pollinated except for three hybrid controls, 2) high to medium yield levels, 3) fruit of medium size, 4) varieties with known disease resistances, especially to *Fusarium* wilt, 5) heat tolerance, and 6) resistance to fruit cracking and blemishes.

The experiment was established using a randomized complete block design with four replications (Fig. A-4 & A-5). Each replication was planted in beds that measured wide 1.8 m by 61 m long. Beds were separated from each other by a 1.8 meter wide grass path, giving a between row spacing of 3.7 m. Each cultivar was planted in a plot of 7 plants at an in-row spacing of 0.6 m. Plot dimensions were 4.3 m long by 1.8 m wide. An extra plant was placed at the ends of each row as a border. All plots were drip irrigated using reusable 1.3 cm polyethylene tubing, with individual one gallon per hour (GPH) emitters.

To enhance biological control of insects a farmscape was planted on both sides of the variety trial (Dufour, 2000). Sunn hemp *(Crotalaria juncea* L.*)* and jack bean (*Canavalia ensiformis* L.*)* were planted in the farmscape beds to provide pollen and nectar sources as well as shelter required by beneficial insects. Sunnhemp has also been shown to act as a catch crop for white flies (Pantoja et al., 1999).

Nursery

Tomato seeds were sown in trays with 50 cells 5 cm deep and 4 cm in diameter. The growing medium consisted of 1 part sphagnum moss, 1 part perlite, and 1 part composted cow manure. One variety was planted per tray. Seeds that did not germinate were replanted. Seedlings were later transplanted into deeper 38 cell trays and weak seedlings were culled. Seedlings were fertilized with Neptune's Harvest™ fish/seaweed emulsion (2-3-1) twice a week with a concentration of 10 ml per liter. Seedlings were also top dressed with 1.5 ml of Bioflora™ granular fertilizer (6-6-5) per cell if nitrogen deficiency was noted.

Organic soil fertility management

Organic soil fertility management strives toward a biologically active soil with improved physical structure and enhanced nutrient availability (Gaskell et al., 2007). This is primarily implemented through practices that increase soil organic matter (Gaskell et al., 2007). Green manure cover cropping, cow manure, yard waste compost, and grass mulch were used as locally available organic matter inputs. Since the mineralization of both nitrogen and phosphorous from organic matter may not be synchronized with crop demand, imported fertility inputs were also used. These included BioVam™ mycorrhizal inoculants, Bioflora™ organic granular fertilizer (6-6-5), and Bioflora™ organic liquid fertilizer (2-1-1).

Bed preparation

Composted cow manure was spread on the experimental beds at a rate of 44 tons per hectare the first season. During the second season, 22 tons per hectare of composted cow manure was mixed with 22 tons per hectare of leaf/grass compost from the University of Puerto Rico Mayaguez Campus, due to insufficient availability of composted cow manure. Typical rates for diary manure applications are 22 to 67 tons per hectare (Sullivan, 2004). At these rates the crop would receive approximately 56 to 168 kg N per hectare (Sullivan, 2004). This is dependent on the age and quality of the manure.

Sunn hemp *(Crotalaria juncea* L.*)* was planted as a green manure cover crop the first season. Due to lack of sunn hemp seed, cowpea (*Vigna unguiculata)* was used the second season. When the first flowers emerged, the plants were incorporated into the soil, approximately 2 months after sowing. Cowpea can produce about 4.5 tons of dry matter per hectare, each ton containing about 27 kg of nitrogen (Valenzuela and Smith, 2002). Sunn hemp can produce over 2.5 tons of biomass and over 112 kg of nitrogen per hectare (USDA, 1999). The amount of nitrogen and biomass produced by the green manure cover crop is dependent on the vigor of the planting.

Transplanting

The field trials were planted in the dry season on February 10, 2010 the first season and January 26 and 27, 2011 the second season. At transplanting, roots were inoculated with 5 ml of BioVam™ mycorrhizal root enhancer. Arbuscular mycorrhizal (AM) fungi from BioVam™ inoculum can help in the absorption of slowly diffusing ions such as phosphorous and zinc (Jacobsen et al., 1992), which were at very low levels at the experimental site. Bioflora™ organic granular fertilizer (6-6-5) was banded around each plant (200 g/plant.), which provided 56 kg of nitrogen per hectare.

Mounding

All tomatoes were mounded 14-21 DAT (days after transplanting) by shoveling soil towards the plant stem. Lower leaves were removed from plants before mounding.

Mounding stabilizes young plants against high winds and stimulates the formation of adventitious roots (Pagaling et al., 1999). It also smothers weeds prior to mulching.

Staking

Tomatoes were staked with one stake per plant after mounding. Two meter lengths of 1.3 cm diameter rebar with 1.5 m exposed supported determinate tomato plants. Three-meter lengths of 1.3 cm diameter rebar supported indeterminate vines with 2.4 m exposed. Water from drip irrigation facilitated the pushing of rebar down into soil. Staking helps to prevent fruit rot by keeping fruit off the ground (Gerber, 1979). It also provides better spray penetration and easier access to fruit during harvest (Pagaling et al., 1999).

Pruning and tying

The standard method of one plant per stake is the most time-consuming training procedure because it requires constant pruning and tying (Gerber, 1979). Pruning involves the selective removal of suckers, the shoots that grow in the leaf axils. Suckers were removed when they were 5 to 10 centimeters long using the thumb and the index finger. Pruning helps to create an optimal balance between vegetative growth and fruit production (Cox, 2011). It also facilitates spraying and harvest operations by opening up the canopy.

Indeterminate tomato plants are pruned more heavily than determinate plants. Indeterminate plants were pruned to approximately 4-5 stem leaders, depending on the amount of foliage. Lack of foliage could lead to physiological leaf curl and fruit sunscald, whereas too much foliage makes training and tying difficult. Determinate bushes were pruned by removing lower branches, which are prone to bending and cracking under fruit load. Lower leaves and suckers were removed from both indeterminate and determinate plants to facilitate mounding and to keep leaves from direct contact with mulch, which could promote leaf fungal diseases.

Mulching

Field cut grass from the experiment station was applied to the beds after mounding and staking. The mulch was applied to a depth of 20 cm. Mulch was used to control weeds, conserve soil moisture, maintain soil tilth, lower soil temperatures and prevent disease transmission. Foliar diseases can spread if water bounces off bare earth, picking up disease causing pathogens and splashing them onto the lower leaves (Diver et al., 1999).

Pest and disease control

In 2010 and 2011, a bi-weekly preventative spray program was used to control disease and insect pests (Tables A-4 & A-5). Once disease or insects become established, control becomes more difficult. All products were OMRI (Organic Materials Research Institute) approved. Foliar applications were applied with a backpack sprayer to the upper and lower surfaces of leaves. Sprays were applied at or around dawn when wind was calm, leaf stomata were open, and there was little beneficial insect activity.

BioVam™ mycorrhizal root enhancer also serves as a biological control for root pathogens. These symbiotic associations have demonstrated direct control for plant diseases caused by *Phytophthora, Rhizoctonia, and Fusarium* pathogens (Dalpe and Monreal, 2003).

Visual field observations were performed on the incidence of insects and diseases throughout the entire season. Plants with virus symptoms were uprooted and eliminated from the field to reduce disease transmission. Roguing of plants with virus symptoms was discontinued after the first harvest.

Foliar nutrition

Tomato foliage was sprayed approximately five times per season with liquid organic fertilizers. Foliar fertilizer applications began at fruit set and continued every two to three weeks throughout the growth cycle of the tomato planting. Several products were used, depending on product availability. Research by Chaurasia et al. (2005) and Premsekhar and Rajashree (2009) found that five foliar applications of water-soluble fertilizer (19-19-

19) along with all the recommended soil nutrients produced the highest growth parameters and yield of hybrid tomatoes. The enhanced productivity due to foliar sprays may be a result of low availability of soil nutrients due to fixation and immobilization (Premsekhar and Rajashree, 2009), and lack of synchrony with crop demand and mineralization rates.

Harvest and yield estimates

Tomatoes were harvested at the breaker stage of development, which is when pink or red color first starts to develop. In the field, tomatoes were weighed and the number of fruits per plot recorded. Fruits were separated as either marketable or unmarketable (culls). Marketable fruits had no defects or gross blemishes and were considered acceptable for sale at the local organic market (Fig. A-6). Marketable fruits were not graded. Culled fruits were not classified by defect, but were due mostly to radial cracking, rebar stake wounds, and insect holes. Culled fruits were considered of no value either commercially or for home use. In 2010, plots were harvested nine times: on April 15, 20, 22, 27, and 30, and on May 10, 14, and 20. In 2011, tomatoes were harvested seven times: on April 7, 12, 19, 25, and 29, and on May 3 and 9.

As part of our organic management plan, all plants exhibiting virus symptoms before the first harvest were eliminated to avoid total crop failure resulting from virus dissemination to healthy plants. Actual marketable yield in tons per hectare reflects the actual plants remaining per plot after roguing infected plants. Actual marketable yield was calculated with the following formula: Actual marketable yield = the average marketable fruit weight/plant × 10,759 plants per hectare × percentage of plants/plot at harvest. At a planting density of 10,759 plants/ha, in row plant spacing would be 0.6 m and between row spacing would be 1.5 m.

Projected marketable yield was based on a 100% plant survival rate. Projected marketable yield was calculated with the following formula: Projected marketable yield = the average marketable fruit weight/plant × 10,759 plants per hectare. This plant population assumes an in-row plant spacing of 0.6 m by 1.5 m. Yield data were analyzed for statistical significance using the Statistix 8.0 analytical software (Tallahassee, Florida).

Tomato quality attributes

Tomato quality attributes were assessed by measuring brix, fruit weight, fruit diameter and height, and through a consumer variety preference survey. Brix values or total soluble solids (TSS) were measured by placing a few drops of tomato juice extract on the prism of a Atago hand held refractometer model number 238342 (Tokyo, Japan). High brix values are often associated with sweeter tasting fruit. Tomatoes with brix values over 6 are uncommon and they are the benchmark for sweet tasting tomatoes with distinctive flavor (Update 10 brix tomato challenge, 2010). Brix values measured in this experiment were not tested for statistical significance due to small sample size (n=5) each season.

Cultivar fruit weight was calculated using the average marketable fruit weight per plant, divided by the average number of marketable fruits. Fruit diameter and fruit length measurements of five representative fruits per cultivar were measured with a hand caliper each season. Fruit diameter and fruit length measurements were not tested for statistical significance due to small sample size (n=5).

A consumer variety preference survey was undertaken on three separate occasions during the harvest (n=23) for both years (Fig. A-7). Tomato samples and a ripe fruit display were presented to adults. Participants were members of the Rincon community with interest in organic products. Fully ripe and representative fruits were displayed on paper plates, which were filled to capacity. Each plate had a numbered code, which corresponded to a particular variety. Bite sized tomato pieces were made available in front of each cultivar's display. Evaluation forms were distributed to all the participants, who scored fruit taste and overall appearance for each cultivar (Fig. A-8). For the fruit quality evaluation, a scale of 1 to 5 was used, where 5=like very much, 4=like, 3=average, 2=dislike, and 1=dislike very much.

Cultivars were ranked on a scale from 1 (high) to 14 (low) for taste, marketable yield per plant and overall fruit appearance. Ranking was based on mean differences and not on statistical differences. If cultivars had the same mean numerical value they were given the same number.

RESULTS

Marketable fruit weight per plant

In 2010, significant differences ($P<0.05$) were found among cultivars for marketable fruit weight per plant (Table 1). ‘Roma’ (6.6 kg), ‘Neptune’ (6.1 kg), ‘BHN 444’ (5.3 kg), and ‘Early Girl’ (4.3 kg) produced greater marketable fruit weight per plant than other cultivars. The average marketable fruit weight per plant ranged from 6.6 kg for ‘Roma’ to 0.8 kg for ‘Marion’. Cultivars with the lowest marketable fruit weight per plant were ‘Marion’, ‘Tropic’ (1.6 kg), ‘Super Sioux’ (2.2 kg), ‘Ace 55’ (2.4 kg) and ‘Eva Purple Ball’ (2.6 kg).

In 2011, significant differences ($P<0.05$) were found among cultivars for marketable fruit weight per plant (Table 2). ‘Early Girl’ (5.1 kg), ‘Flora Dade’ (5.0 kg), ‘BHN 444’ (4.7 kg), ‘Roma’ (4.5 kg), ‘Eva Purple Ball’ (4.5 kg) ‘Traveler 76’ (4.3 kg), and ‘Celebrity’ (3.9 kg) had the highest marketable fruit weight per plant. The average marketable fruit weight per plant ranged from 5.1 kg for ‘Early Girl’ to 2.2 kg for ‘Super Sioux’. Cultivars with the lowest marketable fruit weight per plant were ‘Super Sioux’, ‘Ace 55’ (2.6 kg), and ‘Marion’ (2.6 kg),

Marketable fruit weight per plant was significantly different ($P<0.5$) from year to year as was the cultivar by year interaction. The average marketable fruit weight per plant was higher in 2011 (3.9 kg) than in 2010 (3.5 kg) (Tables 1 & 2). The open pollinated cultivars varied more from year to year than the hybrid controls for marketable fruit weight per plant. Open pollinated cultivars that were high yielders in 2010, like ‘Roma’ and ‘Neptune’, were not in 2011, and low performers in 2010, like ‘Eva Purple Ball’ and ‘Traveler 76’, improved in 2011 (Tables 6 & 7). On average, the top performing cultivars in the two-year trial for marketable fruit weight per plant were ‘Roma’ (5.5 kg), ‘BHN 444’ (5.0 kg), ‘Neptune’ (5.0 kg), and ‘Early Girl’ (4.7 kg). ‘Marion’ (1.6 kg) and ‘Super Sioux’ (2.2 kg) had the lowest marketable fruit weight per plant over the two year study.

Table 1. Marketable fruit weight/plant, total fruit weight/plant, percentage of culls, number of marketable fruits/plant, and total number of fruits/plant of tomato cultivars grown under organic management, 2010-winter/spring season, Agricultural Experiment Station (AES), Lajas, Puerto Rico.

Cultivar	Marketable fruit wt./plant (kg)	Total fruit wt./plant (kg)	% Culls (by weight)	Number of marketable fruits/plant	Total number of fruits/plant
Roma	**6.6 a***	7.3 ab	**9 g**	**122 a**	**138 a**
Neptune	6.1 ab	7.3 ab	17 fg	41 b	52 b
BHN 444	5.3 bc	**7.7 a**	31 d	24 c	38 cd
Early Girl	4.3 cd	5.9 bcd	29 def	37 b	57 b
Celebrity	3.9 de	6.8 abc	45 c	20 cd	41 c
Flora Dade	3.7 def	6.6 abc	44 c	25 c	51 b
Homestead 24	3.5 defg	6.4 abcd	46 c	17 cde	35 cdef
Ozark Pink	3.3 defgh	4.1 ef	18 fg	21 c	29 efg
Traveler 76	3.0 efgh	3.6 f	19 efg	23 c	32 defg
Eva Purple Ball	2.6 fghi	3.6 f	27 def	19 cde	28 fg
Ace 55	2.4 ghi	5.0 de	52 bc	12 ef	27 g
Super Sioux	2.2 hi	5.4 cd	59 b	14 def	36 cde
Tropic	1.6 ij	4.1 ef	61 b	**9 f**	**25 g**
Marion	**0.8 j**	**2.7 fg**	**73 a**	**9 f**	**25 g**
Average	**3.5**	**5.5**	**38**	**28**	**44**

*Means in a column followed by the same letters are not significantly different at P=0.05 level by Fisher's LSD test.

Table 2. Marketable fruit weight/plant, total fruit weight/plant, percentage of culls, number of marketable fruits/plant, and total number of fruits/plant of tomato cultivars grown under organic management, 2011-winter/spring season, AES, Lajas, Puerto Rico.

Cultivar	Marketable fruit wt./plant (kg)	Total fruit wt./plant (kg)	% Culls (by weight)	Number of marketable fruits/plant	Total number of fruits/plant
Early Girl	**5.1 a***	**7.3 a**	30 cd	40 b	67 b
Flora Dade	5.0 a	**7.3 a**	30 cd	28 bcd	47 bc
BHN 444	4.7 a	6.8 ab	30 cd	22 bcd	32 c
Roma	4.5 a	5.4 abcd	**5 e**	**75 a**	**96 a**
Eva Purple Ball	4.5 a	5.4 abcd	20 d	25 bcd	41 c
Traveler 76	4.3 ab	5.4 abcd	22 d	26 bcd	35 c
Celebrity	4.3 ab	**7.3 a**	42 bc	21 cd	37 c
Homestead 24	3.8 abc	5.9 abcd	27 d	17 cd	27 cd
Ozark Pink	3.8 abc	**5.0 bcd**	20 d	23 bcd	32 c
Tropic	3.5 abcd	6.6 abc	46 ab	15 cd	37 c
Neptune	3.5 abcd	**5.0 bcd**	27 d	30 bc	32 c
Marion	2.6 cde	5.9 abcd	**57 a**	16 cd	39 c
Ace 55	2.6 cde	**5.0 bcd**	51 ab	**11 d**	**24 cd**
Super Sioux	**2.2 de**	**5.0 bcd**	56 a	14 cd	37 c
Average	**3.9**	**6.0**	**33.1**	**26**	**42**

*Means in a column followed by the same letters are not significantly different at P=0.05 level by Fisher's LSD test.

Percentage of culled (unmarketable) fruit by weight

In 2010, significant differences ($P<0.05$) were found among cultivars for the percentage of culled fruit by weight (Table 1). ‘Roma’ (9%), ‘Neptune’ (17%), ‘Ozark Pink’ (18%), and ‘Traveler 76’ (19%) produced less culled fruit as a percentage of total yields than other cultivars. The average percentage of culled fruit by weight ranged from 9% for ‘Roma’ to 73% for ‘Marion’. Cultivars that produced the most culled fruit by weight were ‘Marion’, ‘Tropic’ (61%), ‘Super Sioux’ (59%) and ‘Ace 55’ (52%). In 2010, radial fruit cracking, followed by caterpillar damage, were the most common cause of culled fruit.

In 2011, significant differences ($P<0.05$) were found among cultivars for the percentage of culled fruit by weight (Table 2). Cultivars that produced the least culled fruit as a percentage of total yield were ‘Roma’ (5%), and all the pink tomatoes, ‘Eva Purple Ball’ (20%), ‘Ozark Pink’ (20%), and ‘Traveler 76’ (22%). The average percentage of culled fruit by weight ranged from 5% for ‘Roma’ to 57% for ‘Marion’. Cultivars that produced the most culled fruit by weight were ‘Marion’, ‘Super Sioux’ (56%), ‘Ace 55’ (51%), and ‘Tropic’ (46%). In 2011, radial cracking was the most common cause of culled fruit.

The percentage of culled fruit by weight was significantly different ($P<0.5$) between years, with 38% culls in 2010, and 33% culls in 2011. ‘Homestead’, ‘Marion’ and ‘Tropic’ had at least 15% more culled fruit by weight in 2010 then in 2011 (Tables 1 & 2). Over the two-year study cultivars with greater than 50% culled fruit included ‘Marion’ (65%), ‘Super Sioux’ (57%), ‘Tropic’ (54%), and ‘Ace 55’ (51%). Cultivars with a high percentage of culled fruits will have limited commercial value. Overall, the cultivars with the least amount of culled fruit included ‘Roma’ (7%), ‘Ozark Pink’ (19%), and ‘Traveler 76’ (21%).

Number of marketable fruits per plant

In 2010, significant differences ($P<0.05$) were found among cultivars in the number of marketable fruits per plant (Table 1). The mean number of marketable fruits per plant ranged from 122 for ‘Roma’ to 7 for ‘Marion’. ‘Roma’, the only cultivar with a small plum-type fruit, produced significantly (P<0.05) more fruits per plant than all other cultivars. ‘Marion’, ‘Tropic’ (9), and ‘Ace 55’ (12) were the lowest yielding.

In 2011, significant differences (P<0.05) were found among cultivars for number of marketable fruits per plant (Table 2). The total number of marketable fruits per plant ranged from 75 for ‘Roma’ to 11 for ‘Ace 55’. ‘Roma’ produced significantly (P<0.05) more marketable fruits per plant than all other cultivars. ‘Ace 55’, ‘Marion (12), ‘Super Sioux’ (14), and ‘Tropic (15) were the lowest yielding.

Over the two-year study, the top two cultivars with the highest number of marketable fruits per plant were also those with the smallest fruit weight. ‘Roma’ (99), and ‘Early Girl’ (40) produced the greatest number of marketable fruits per plant. ‘Marion’ (11), ‘Ace 55’ (11), ‘Tropic’ (14), and ‘Super Sioux’ (15) had the smallest number of fruits per plant.

Actual marketable yield

In 2010, significant differences (P<0.05) were found among cultivars for actual marketable yield (Table 3). The incidence of viral infection was low in 2010; consequently actual marketable yields were similar to projected marketable yields. ‘Roma’ (72.1 t/ha), ‘Neptune’ (56.8 t/ha), and ‘BHN 444’ (56.2 t/ha), had the greatest actual marketable yields. The actual marketable yield ranged from 72.1 t/ha for ‘Roma‘ to 8.6 t/ha for ‘Marion’. Cultivars that yielded the least were ‘Marion’ and ‘Tropic’ (16 t/ha).

In 2011, significant differences (P<0.05) were found among cultivars for actual marketable yield (Table 4). Also, the incidence of viral infection before first harvest was high and consequently there were large differences between actual marketable yield and projected marketable yield. ‘Flora Dade’ (46.1 t/h), ‘BHN 444’ (43.5 t/h), and ‘Celebrity’ (38.3 t/ha) had the greatest actual marketable yields. The actual marketable yield ranged from 46.1 t/ha for ‘Flora Dade’ to 8.7 t/ha for ‘Roma’. Cultivars that yielded the least were ‘Roma’, ‘Marion’ (17.1 t/h), ‘Traveler 76’ (21.5 t/h), ‘Super Sioux’ (21.8 t/h) and ‘Ozark Pink’ (22.2 t/h). The poor performance of ‘Roma’ in 2011 was due to extreme virus susceptibility, leading to 82% loss of plants due to roguing (Table 9).

Table 3. Actual marketable yield (t/ha), average number of plants per plot, percentage of plants eliminated before first harvest due to virus symptoms, and projected marketable yield (t/ha), 2010 organic tomato variety trial, AES, Lajas, Puerto Rico

Cultivar	Actual Marketable Yield (t/ha)**	Average No. of Plants/Plot	% Plants Rogued due to Virus Symptoms	Projected Marketable Yield (t/ha)***
Roma	**72.1 a***	7	0	**72.1 a**
Neptune	56.8 ab	6.3	11	65.6 ab
BHN 444	56.2 bc	7	0	56.2 bc
Early Girl	44.8 cd	6.8	4	46.4 cd
Celebrity	41.8 de	7	0	41.8 de
Flora Dade	39.9 def	7	0	39.9 def
Homestead 24	38.1 def	7	0	38.1 def
Ozark Pink	33.9 defg	6.8	4	35.3 defg
Traveler 76	28.3 efg	6.3	11	32.2 efg
Eva Ball Purple	26.8 fgh	6.8	4	28.0 fgh
Ace 55	23.3 gh	6.5	7	25.3 gh
Super Sioux	23.2 gh	6.8	4	23.9 gh
Tropic	16.0 hi	6.5	7	17.1 hi
Marion	**8.6 i**	7	0	**8.6 i**
Average	**36.4**	**6.8**	**2.9**	**37.9**

*Means in a column followed by the same letters are not significantly different at P=0.05 level by Fisher's LSD test
**Actual marketable yield=avg. fruit wt./plant × 10,759 plants/ha × percentage of plants/plot at harvest.
***Projected marketable yield=avg. fruit wt./plant × 10,759 plants/ha (0.6 m × 1.5 m spacing; 100% plant population)

Table 4. Actual marketable yield (t/ha), average number of plants per plot, percentage of plants eliminated before first harvest due to virus symptoms, and projected marketable yield (t/ha), 2011 organic tomato variety trial, AES, Lajas, Puerto Rico

Cultivar	Actual Marketable Yield (t/ha)**	Average No. Plants/Plot	% Plants Rogued due to Virus Symptoms	Projected Marketable Yield (t/ha)***
Flora Dade	**46.1 a***	6	15	53.8 a
BHN 444	43.5 ab	6	15	50.8 a
Celebrity	38.3 abc	5	29	45.9 ab
Tropic	34.7 bc	4.5	36	38.5 abcd
Neptune	31.3 bc	5.8	18	38.1 abcd
Early Girl	29.3 bc	3.8	46	**54.7 a**
Ace 55	25.8 c	6.5	7	27.8 cde
Homestead 24	24.9 c	4.25	39	41.0 abc
Eva Purple Ball	24.2 cd	3.5	50	48.4 a
Ozark Pink	22.2 cd	3.8	46	41.0 abc
Super Sioux	21.8 cd	6.5	7	**23.5 de**
Traveler 76	21.5 cd	3.3	54	46.4 a
Marion	17.1 cd	4.3	39	28.2 cde
Roma	**8.7 d**	1.3	82	48.6 a
Average	**27.8**	**4.59**	**34.6**	**46.6**

*Means in a column followed by the same letters are not significantly different at P=0.05 level by Fisher's LSD test.
**Actual marketable yield=avg. fruit wt./plant × 10,759 plants/ha × percentage of plants/plot at harvest
***Projected marketable yield=avg. fruit wt./plant × 10,759 plants/ha (0.6 m × 1.5 m spacing; 100% plant population)

Projected marketable yield

In 2010, significant differences ($P<0.05$) were found among cultivars for projected marketable yield (Table 3). 'Roma' (72.1 t/ha), 'Neptune' (65.6 t/ha), and 'BHN 444' (56.2 t/ha) had the highest projected marketable yields, which didn't differ or varied little from actual yields because no or few plants were rogued. The projected marketable yield ranged from 72.1 (t/ha) for 'Roma' to 8.6 (t/ha) for 'Marion'. Cultivars with the lowest projected marketable yields were 'Marion' and 'Tropic' (17.1 t/ha).

In 2011, significant differences ($P<0.05$) were found among cultivars for actual marketable yield (Table 4). Differences between actual marketable yield and projected marketable yield were greater due to more roguing of virus infected plants. 'Early Girl' (54.7 t/h), 'Flora Dade' (53.8 t/h), 'BHN 444' (50.8 t/h), 'Roma' (48.6 t/h), 'Eva Purple Ball' (48.4 t/h), 'Traveler 76' (46.4 t/h), and 'Celebrity' (45.9 t/h) all had high projected yields. Projected marketable yield ranged from 54.7 (t/ha) for 'Early Girl' to 23.5 (t/ha) for 'Super Sioux'. Cultivars with the lowest projected marketable yields were 'Super Sioux', 'Ace 55' (27.8 t/ha) and 'Marion' (28.2 t/ha). Projected marketable yields represent the potential yield of each cultivar in the absence of virus infection or other sources of plant population decline.

Timing of harvest

Table 5 shows all harvests distributed into three time periods: beginning of harvest until 75 days after transplanting (DAT) (early season), 75 to 87 DAT (midseason), and 88 to 101 DAT (late season). A cultivar was classified to a specific season when 60% of its total marketable fruit was harvested in one of the season categories. In this study, there were no varieties classified as early season. If 60% of fruit was harvested before 87 DAT it was considered midseason. If 60% of fruit was harvested after 88 DAT it was considered a late season variety. If there was relatively equal distribution between midseason and late season the variety was classified as mid/late season.

In both 2010 and 2011 seasons, the pink-fruited tomatoes ('Eva Purple Ball', 'Ozark Pink', and 'Traveler 76') were all classified as late season tomatoes (Table 5). Other varieties that were classified the same way each season were 'Super Sioux'

Table 5. Percentage of marketable fruit per harvest period of tomato cultivars grown under organic management, 2010/2011 winter/spring season, AES, Lajas, Puerto Rico

Cultivars **2010**	*Harvests before 75 DAT*	*Harvests 76 thru 87 DAT*	*Harvests 88 thru 101DAT*	**Harvest Maturity*
Ace 55 (D)***	11%	27%	**62%**	Late
BHN 444 (D)	12%	**53%****	35%	Midseason
Celebrity (D)	13%	**52%**	35%	Midseason
Early Girl (I)	22%	34%	**44%**	Mid/Late
Eva Purple Ball (I)	7%	26%	**67%**	Late
Flora Dade (D)	7%	43%	**50%**	Mid/Late
Homestead 24 (D)	13%	**44%**	43%	Mid/Late
Marion (I)	4%	17%	**79%**	Late
Neptune (D)	10%	35%	**55%**	Mid/Late
Ozark Pink (I)	5%	29%	**66%**	Late
Roma (D)	10%	**45%**	**45%**	Mid/Late
Super Sioux (I)	9%	**51%**	40%	Midseason
Traveler 76 (I)	2%	26%	**72%**	Late
Tropic (I)	5%	31%	**64%**	Late
Average	9.3%	36.6%	54.1%	
2011				
Ace 55 (D)	7%	38%	**55%**	Mid/Late
BHN 444 (D)	12%	**45%**	43%	Mid/Late
Celebrity (D)	7%	**50%**	43%	Mid/late
Early Girl (I)	17%	**52%**	31%	Midseason
Eva Ball Purple (I)	5%	28%	**67%**	Late
Flora Dade (D)	1%	29%	**70%**	Late
Homestead 24 (D)	5%	42%	**53%**	Mid/Late
Marion (I)	15%	**53%**	32%	Midseason
Neptune (D)	5%	35%	**60%**	Late
Ozark Pink (I)	3%	27%	**70%**	Late
Roma (D)	2%	25%	**73%**	Late
Super Sioux (I)	14%	**56%**	30%	Midseason
Traveler 76 (I)	2%	22%	**76%**	Late
Tropic (I)	3%	34%	**63%**	Late
Average	7%	38.3%	54.7%	

**Midseason=60% harvest before 88 DAT. Late season=60% after 88 DAT. Mid/late season=relatively equal distribution before and after 88 DAT.*
***Percentages in bold type represent the primary harvest season for each cultivar.*
****(D)=determinate, and (I)=indeterminate*

(midseason), ‘Homestead 24’ (mid/late season) and ‘Tropic’ (late season). All other cultivars varied in their timing of maturation in this two year comparison.

Consumer preference evaluation

Taste and overall fruit appearance evaluations were made on all varieties by a panel of adults (Fig. A-3). In 2010, ‘Ace 55’ (4.4) and ‘Early Girl’ (4.1) were judged to have better tasting fruit than all other cultivars, followed by ‘Celebrity’, ‘Ozark Pink’, and ‘Super Sioux’, all of which had a score of 3.9 (Table 6). The average taste test scores ranged from 4.4 for ‘Ace 55’ to 2.8 for ‘BHN 444’. The average taste test score for ‘BHN 444’ was less than all other cultivars.

In 2011, ‘Early Girl’ (4.4) and ‘Super Sioux’ (4.2) were judged to have better tasting fruit than all other cultivars, followed by ‘Ace 55’, ‘Eva Purple Ball’, and ‘Marion’, all of which had a score of 4.0 (Table 6). The average taste test scores ranged from 4.4 for ‘Early Girl’ to 2.6 for ‘Neptune’. The average taste test score for ‘Neptune’ and ‘Roma’ (3.0) were lower than for other cultivars.

Table 6. Consumer preference survey results for fruit taste and overall fruit appearance of tomato cultivars grown under organic management, 2010/ 2011 winter/spring seasons, AES, Lajas, Puerto Rico. Rating scale; 5=like very much, 4=like, 3=average, 2=dislike, 1=dislike very much

Cultivar	*Fruit taste*		*Overall fruit appearance*	
	2010	2011	2010	2011
Ace 55	**4.4 a***	4.0 abc	4.1 bc	3.6 cde
BHN 444	**2.8 e**	3.7 bcd	4.0 bcd	3.9 bcd
Celebrity	3.9 abc	3.8 bc	3.7 cde	3.8 bcde
Early Girl	4.1 ab	**4.4 a**	**4.8 a**	**4.7 a**
Eva Purple Ball	3.5 cd	4.0 abc	3.8 cd	4.0 bc
Flora Dade	3.5 cd	3.2 de	3.8 cd	**3.4 e**
Homestead 24	3.6 bcd	3.8 bc	4.1 bc	3.9 bcd
Marion	3.7 bc	4.0 abc	**2.4 f**	**3.4 e**
Neptune	3.5 cd	**2.6 f**	4.3 ab	4.1 b
Ozark Pink	3.9 abc	3.9 bc	3.6 de	4.1 b
Roma	3.6 bcd	3.0 ef	3.9 bcd	4.1 b
Super Sioux	3.9 abc	4.2 ab	3.2 e	3.5 de
Traveler 76	3.8 bc	3.7 bcd	3.7 cde	4.2 ab
Tropic	3.8 bc	3.9 bc	4.0 bcd	4.0 bc
Average	**3.7**	**3.7**	**3.8**	**3.9**

*Means in a column followed by the same letters are not significantly different at P=0.05 level by the LSD test.

In 2010, ‘Early Girl’ (4.8) and ‘Neptune’ (4.3) were judged to have fruit of better overall appearance than all other cultivars, followed by ‘Ace 55’ (4.1), ‘Homestead 24’ (4.1), ‘BHN 444’ (4.0) and ‘Tropic’ (4.0) (Table 6). The average overall appearance scores ranged from 4.8 for ‘Early Girl’ to 3.2 for ‘Super Sioux’. Cultivars with the lowest overall appearance scores were ‘Super Sioux’ and ‘Ozark Pink’ (3.6).

In 2011, ‘Early Girl’ (4.7) and ‘Traveler 76’ (4.2) were judged to have fruit of better overall appearance than other cultivars, followed by ‘Neptune’ (4.1), ‘Ozark Pink (4.1), and ‘Roma’ (4.1). The average overall appearance scores ranged from 4.7 for ‘Early Girl’ to 3.4 for cultivars ‘Flora Dade’ and ‘Marion’. Cultivars with the lowest overall appearance scores were, ‘Flora Dade’ and ‘Marion’, and ‘Super Sioux’ (3.5).

Fruit brix values

In 2010, the cultivars with the highest brix ratings were as follows: ‘Early Girl (5.3), ‘Eva Purple Ball’ (4.8), and ‘Super Sioux (4.7). The brix ratings ranged from 5.3 for ‘Early Girl’ to 3.4 for ‘Roma’ (Table 7). ‘Early Girl’ had the highest brix value of any individual fruit. This 6.0 brix tomato was decidedly sweeter than any other samples. The average brix value for all the cultivars was 4.3, which is the same as that reported by Palada and Davis (2001) for 12 hybrid tomato cultivars grown under organic management in the U.S Virgin Islands.

In 2011, the cultivars with the highest brix ratings were as follows: ‘Early Girl’ (5.3), ‘Ozark Pink’ (4.8), and ‘Tropic’ (4.8). The brix ratings ranged from 5.3 for ‘Early Girl’ to 3.9 for ‘Neptune’ (Table 7). ‘Early Girl’ again had a 6 brix tomato, which was the highest value of the year, and the sweetest in taste. The average brix value for all the cultivars was 4.5.

Fruit weight

In 2010, significant differences ($P<0.05$) were found among cultivars for the average weight per fruit (Table 7). ‘BHN 444’ (224 g) and ‘Homestead 24’ (211 g) produced fruit of greater weight than other cultivars, followed by ‘Ace 55’ (198 g) and ‘Celebrity’ (194 g). The average weight per fruit ranged from 224 g for ‘BHN 444’ to 55 g for ‘Roma’.

‘Marion (112 g), and ‘Early Girl’ (117 g) also produced fruit of less weight than other cultivars.

In 2011, significant differences (P<0.05) were found among cultivars for the average weight per fruit (Table 7). ‘Ace 55’ (236 g), ‘BHN 444’ (224 g), and ‘Homestead 24’ (223 g) produced fruit of greater weight than other cultivars, followed by ‘Celebrity’ (205 g) and ‘Tropic’ (184 g). The average weight per fruit ranged from 236 g for ‘Ace 55’ to 60 g for ‘Roma’. ‘Roma’, and ‘Early Girl’ (116 g) produced fruit of less weight than other cultivars. They were also among the top yielders for marketable fruit per plant.

There was no significant interaction for cultivars fruit weight between years. Overall, ‘BHN 444’ (224 g) and ‘Ace 55’ (217 g) produced fruit of greater weight than all other cultivars. ‘Roma’ (58 g) and ‘Early Girl’ (117 g) produced fruit of less weight than all other cultivars. The average fruit weight for all the cultivars was less in 2010 (157 g) than in 2011 (165 g). In 2010, there were a greater average number of marketable fruits per plant than in 2011, which may have contributed to lower individual fruit weight in 2010.

Table 7. Brix (total soluble solids), fruit weight, fruit diameter, and fruit height of tomato cultivars grown under organic management, 2010/2011-winter/spring seasons, AES, Lajas, Puerto Rico.

Cultivar	*Brix***		*Fruit Weight (g)*		*Diameter** (cm)*		*Height** (cm)*	
	2010	2011	2010	2011	2010	2011	2010	2011
Ace 55	4.6	4.7	198 abc*	**236 a**	7.9	**8.4**	6.1	6.4
BHN 444	3.6	4.5	**224 a**	224 ab	7.4	8.1	**7.4**	**7.4**
Celebrity	4.4	4.2	194 bc	205 abc	7.4	7.4	6.1	6.1
Early Girl	**5.3**	**5.3**	117 gh	116 e	6.1	6.4	**5.3**	**5.6**
Eva Purple Ball	4.8	4.7	141 efg	141 de	6.4	6.6	**5.3**	5.8
Flora Dade	3.7	4.0	150 ef	161 cde	6.4	7.6	6.1	5.8
Homestead 24	4.6	4.1	211 ab	223 ab	**8.1**	8.1	6.4	6.6
Marion	4.5	4.6	112 h	163 cde	6.1	6.6	**5.3**	**5.6**
Neptune	4.3	**3.9**	151 ef	117 e	6.9	7.4	5.6	**5.6**
Ozark Pink	4.4	4.8	162 de	165 cde	7.4	6.9	6.1	5.8
Roma	**3.4**	4.7	**55 i**	**60 f**	**4.8**	**4.1**	6.6	6.9
Super Sioux	4.7	4.7	159 def	157 de	6.9	**8.4**	5.8	5.8
Traveler 76	3.8	4.6	133 fgh	165 cde	6.4	6.6	5.8	**5.6**
Tropic	4.4	4.8	185 cd	184 bcd	7.6	7.9	6.4	6.1
Average	**4.3**	**4.5**	**157**	**166**	**6.9**	**7.1**	**6.4**	**6.4**

* Means in a column followed by the same letters are not significantly different at P=0.05 level by the LSD test.
**Statistical analyses were not conducted due to small sample size (n=5 fruits per cultivar).

Fruit diameter and height

In 2010, fruit diameter ranged from 8.1 cm for ‘Homestead 24’ to 4.8 cm for ‘Roma’ (Table 7). In 2011, fruit diameter ranged from 8.4 cm for ‘Ace 55’ to 4.1 cm for ‘Roma’. ‘Roma’, the only plum style tomato in the experiment, had fruit of less diameter than all other cultivars

In 2010, fruit height ranged from 7.4 cm for ‘BHN 444’ to 5.3 cm for ‘Early Girl’, ‘Eva Purple Ball’ and ‘Marion’ (Table 7). In 2011, fruit height ranged from 7.4 cm for ‘BHN 444’ to 5.6 cm for ‘Early Girl’, ‘Marion’, ‘Neptune’, and ‘Traveler 76’.

In 2010, ‘BHN 444’ had fruit of equal diameter (7.4 cm) and height (7.4 cm). Fruit of relatively equal height and diameter are considered globe shaped. In 2011, ‘Ace 55’ had the greatest difference between fruit diameter (8.4 cm) and height (6.4 cm). Fruit with a large diameter and short height are considered oblong fruits.

Cultivar ranking based on taste, marketable yield/plant, and overall fruit appearance

In 2010, ‘Early Girl’ ranked highest overall for taste, yield, and overall fruit appearance (Table 8). The ranking ranged from 1 for ‘Early Girl’ to 10 for ‘Marion’. The top 3 ranking cultivars were ‘Early Girl’ (1), ‘Roma’ (2) and ‘Neptune’ (2).

In 2011, ‘Early Girl’ once again ranked highest overall for taste, yield, and overall fruit appearance (Table 9). The ranking ranged from 1 for ‘Early Girl’ to 9 for ‘Marion’ and ‘Neptune’. The top 4 ranking cultivars were ‘Early Girl’ (1), followed by the pink tomatoes ‘Eva Purple Ball’ (2), ‘Traveler 76’ (3), and ‘Ozark Pink’ (4).

‘Early Girls’ superior ranking can be traced to its high brix fruit values, deep shiny red blemish-free fruits, and its high yields. Yet, ‘Early Girl’ was not without its flaws. In 2011, ‘Early Girl’ had a high incidence of virus infection at 46%, which was 11% higher than the average. Also, towards the end of its harvest, ‘Early Girls’ fruits become noticeably smaller and fruit quality declines.

Table 8. Cultivar ranking of the 2010 organic variety trial, AES, Lajas, Puerto Rico. Scores range from 1=high to 14=low.

Cultivar	*Taste*	*Yield/Plant*	*Appearance*	**Raw Score*	*Ranking.*
Early Girl	2	4	1	7	1
Roma	6	1	5	12	2
Neptune	8	2	2	12	2
Ace 55	1	11	3	15	3
Celebrity	3	5	7	15	3
BHN 444	9	3	4	16	4
Homestead 24	6	7	3	16	4
Flora Dade	7	6	6	19	5
Ozark Pink	3	8	9	20	6
Traveler 76	4	9	7	20	6
Tropic	4	13	5	22	7
Eva Purple Ball	7	10	6	23	8
Super Sioux	3	12	9	24	9
Marion	5	14	10	29	10

*The raw score is based on numerical differences, not statistically significant differences.

Table 9. Cultivar ranking of the 2011 organic variety trial, AES, Lajas Puerto Rico. Scores ranged from 1-high to 14-low

Cultivar	*Taste*	*Yield/Plant*	*Appearance*	**Raw Score*	*Ranking*
Early Girl	1	1	1	3	1
Eva Purple Ball	3	4	4	11	2
Traveler 76	6	5	2	13	3
Ozark Pink	4	7	3	14	4
BHN 444	7	3	5	15	5
Roma	9	4	3	16	5
Tropic	4	8	4	16	5
Celebrity	5	6	6	17	6
Homestead 24	5	7	5	17	6
Ace 55	3	9	7	19	7
Flora Dade	8	2	9	19	7
Super Sioux	2	10	8	20	8
Marion	3	9	9	21	9
Neptune	10	8	3	21	9

*The raw score is based on numerical differences, not statistically significant differences.

DISCUSSION

Tomato yield and quality were traits that were quantified and evaluated in the Lajas organic tomato variety trial. A tomato cultivar needs to have good yields and fruit of high quality to be economically viable to a farmer. This study has shown that yield and quality may be influenced by the genetic makeup of a plant because there were significant differences between cultivars for yield and quality attributes. Cultivars differed amongst each other for marketable fruit weight per plant, the percentage of culled fruit by weight, the number of marketable fruits per plant, brix values, fruit weight, fruit taste, overall fruit appearance, and fruit dimensions.

A tomato cultivar's genetic potential for yield and quality is directly influenced by the health and productivity of a particular farm system. A cultivar can fulfill its genetic potential for yield and quality only under optimal conditions. Organic farmers must manage farm inputs and labor in a timely and intuitive manner in order to optimize productivity. Any mistakes made early on in the production process can significantly compromise yield and quality. Factors which may have contributed to reduced yield and quality performance in the 2010/2011 organic variety trials in Lajas were: the criteria for cultivar selection, the green manure plantings, transplanting dates, seedling care, fruit cracking, insect control, and the incidence of virus infection.

Criteria for cultivar selection

The decision about what tomato cultivar to grow is perhaps more complex than for other crops (Schonbeck et al., 2006). This is because of the different growth habits, time to maturity, size, shape, culinary uses, open-pollinated vs. hybrid, color, flavor, disease resistances, yield potential, and tolerance to physiological disorders and abiotic stresses. When deciding which cultivars to screen in a variety trial, one should take into account the local soils and weather, the management system and market preferences. Assembling potentially well-adapted cultivars for a variety trial can significantly improve the outcome.

The selection criteria for the organic variety trial at Lajas were as follows: cultivars were open-pollinated except for three hybrid controls, had high to medium yield levels, the fruit was of medium size, they possessed disease resistance, especially to *Fusarium* wilt, were heat tolerant, and had resistance to fruit cracking and blemishes.

Heat tolerance may not have been necessary as a selection criterion. Tomato fruit set can be disturbed if maximum day/night temperatures reach levels higher than 32/21°C or 90/70°F (Peet and Bartholemew, 1996). The optimum mean daily temperature for tomato ranges from 21 to 24°C (70 to 75°F), and temperatures a few degrees above the optimum can reduce fruit set (Sato et al., 2001). Fruit set during both trials occurred in the month of February with an average mean temperature of 23.3°C or 73.9°F, which is within the optimal fruit set range. According to 30-year average temperatures compiled in Table A-1, fruit set should, on average, not be interrupted in the cooler months of December-March where mean daily temperatures do not exceed 24°C (75°F). Future organic tomato variety trials may consider substituting exceptional flavor for heat tolerance as a selection criterion during the cool months of winter. Results from the preference survey and informal communication with customers at the farmers market in Rincon both indicate that a high value placed on taste and blemish free fruits.

This trial screened only a small percentage of the open pollinated varieties available. There is a need to trial more suitable cultivars under organic management, so we can access the best regionally adapted cultivars available on the market. Potential researchers may consider having an observational organic variety trial before a replicated trial. Observational trials can screen large numbers of cultivars in one experiment. This could greatly improve the efficiency of the replicated trial by “weeding-out” all the lowest performing cultivars. Also, an observational trial can help refine the organic management plan before the replicated trial.

Organic soil management system

Well-adapted cultivars are of limited use without maintaining or improving soil health and fertility, and without skilled and timely management (Juroszek et al., 2007). In the agro-ecological approach of organic farming, soil fertility is maintained by mimicking the natural ecosystem. This includes soil conservation through vegetative cover, the regular addition of organic matter, and nutrient recycling systems from crop rotation and livestock systems. The major challenge of organic farming is the assembly and skilled management of all the component parts in the farm system.

In the 2010 and 2011 organic variety trials in Lajas, problems were encountered in the planting of the green manure cover crops, which may have influenced yield and quality performance of the tomato cultivars. Heavy rains in the months of September and October made bed preparation difficult, because the soil becomes sticky when wet. Green manure plantings were delayed until November. In 2011, the soil was tilled when wet, which resulted in soil clodding. A lack of rain delayed cover crop germination and the heavy clods reduced plant populations. Due to untimely planting and poor bed preparation, sunn hemp and cowpea did not develop sufficient biomass to provide maximum benefits. Ideally, cover crops should be planted in a well-prepared bed during a seasonally dry period in June/July (Table A-1). The cover crop would grow towards the end of the rainy season (August-October), and be incorporated into the soil during a dry period in October/November. Tomato transplants would be planted 2 to 3 weeks after cover crop incorporation. The timing of cover crop plantings and their incorporation should coincide with optimal transplanting dates for the tomato crop.

Optimal transplanting dates

In southwestern Puerto Rico the year is divided into two seasons, a rainy season between May and November and a dry season between December and April. During the rainy season, high temperature, flooding, and disease can limit tomato production (Palada et al., 2003). In the tropics, tomatoes are regularly planted in the dry season. Peak market value at the local farmers market in Rincon, Puerto Rico is during peak tourist season, which runs from December thru March. Since tomatoes bear fruit from 60 to 100 DAT, the most advantageous transplanting dates would range from October thru December. Organic farmers can then have fresh market tomatoes available in the months of December thru March in order to receive optimal market prices for their tomatoes.

The planting dates of the 2010 and 2011 organic tomato variety trials were delayed due to the late planting of the green manure cover crops. This delayed our tomato transplanting and harvest dates, which may have contributed to reduced yield and quality performance of the tomato cultivars. The month of May in the Lajas region is characterized by heavy rains and increasing mean daily temperatures (Table A-1). Heavy rain and high temperatures have been shown to increase the incidence of fruit cracking (Peet and Willitis, 1995). In both 2010 and 2011, heavy rains coupled with soil of low permeability, increased the incidence of fruit cracking in the end of April into May. By transplanting tomatoes in the months of October thru December, growers can avoid harvesting tomatoes during the heavy rains of May.

Seedling health

Organic farming systems aim at decreasing disease pressure by avoiding stress during crop development (Lammerts van Bueren, 2003). If cultural conditions are kept at optimal levels, plants can resist disease and mature rapidly (Jones, 1999). In both 2010 and 2011, tomato transplants were not grown under optimal conditions. During the Christmas holidays, tomato transplants were given intermittent care and suffered from nutrient deficiency and water deprivation, which may have contributed to reduced yield and quality performance of the tomato cultivars. During the second season, most cultivars developed spots on their leaves in the nursery. Tomato transplants were kept next to sweet pepper transplants in the nursery, which also had spots on their leaves. Due to these leaf spots, fungicides were sprayed on the plants bi-weekly for the entire harvest (Table B-5). These fungicidal sprays could possibly have been avoided if optimal conditions were provided to the seedlings from the beginning. Mistakes made during transplant production may have contributed to problems throughout the entire season.

Fruit cracking and culled fruit

Tomato fruit cracking can significantly affect yield and quality performance. In the 2010 and 2011 organic variety trials at Lajas, fruit cracking was a major problem for some cultivars. The overall percentage of cracked fruit was 38% in 2010 and 33% in

2011. These figures are comparable to Palada and Davis (2001) organic variety trial in the U.S. Virgin Islands. In 1999, they had 29% culled fruit and 36% in 2000.

Fruit cracking can be reduced through cultivar resistance (Jones, 1999) and management strategies. Cultivar crack resistance might be due to morphological adaptations, like an elastic cuticle layer (Cheryld et al., 1997). This indicates that fruit cracking may be under genetic influence. Peet and Willitis (1995) reported that extremes in water supply, high light intensity and high temperatures could cause fruit cracking. To help reduce fruit cracking, especially when heavy rains are predicted, fruit can be harvested less ripe. Harvesting tomatoes in the cool/dry months of winter, along with controlled irrigation practices, may help to reduce the incidence of fruit cracking. In this experiment, tomato plants were trained to a single stake with heavy sucker removal and leaf pruning. This practice could expose the tomatoes to higher temperatures and accelerate fruit cracking. Caging tomatoes could be an alternative to staking. Caged tomatoes have a higher ratio of foliage to fruit because they require little pruning. Plants with more foliage can shield fruit from excessive heat.

Insect control

The silverleaf whitefly (*Bemisia argentifolii)* is a major insect pest, which affects tomato production in Puerto Rico (Pantoja et al., 1999). Left uncontrolled, whiteflies can reduce yields by sucking the sap out of leaves, or by transmitting viruses. Our strategy for control was twofold. First, establish a farmscape two months prior to planting. Sunn hemp (*Crotalaria juncea* L.) was used as a catch crop and as a refuge for whitefly natural enemies (Pantoja et al.,1999) . Next, we used botanical insecticides on a regular basis to keep whitefly populations down (Tables B-4 and B-5). Ecotrol™, a rosemary preparation, and Aza-direct™, made from neem seed, were effective knockdown insecticides. The second season, whitefly populations were less severe, possibly due to yearly pest variation, better control measures, or different nutrient status of the tomato planting.

Armyworms (*Spodoptera frugiperda)* were a major pest the first season. This infestation, which compromised tomato yield and quality, may have been influenced by the use of old Bt insecticide of low viability, a corn planting adjacent to the tomato crop, yearly pest variation, nutrient status of the tomato crop, and/ or better management the second season. During the first season, Bt was applied to transplants for cutworms and armyworms when damage was observed. The second season it was applied as a preventative. In both seasons, caterpillar activity slowed down during the vegetative cycle of tomato growth and increased during the fruiting cycle. The first season Bt was applied as a knockdown insecticide for tomato hornworm (*Manduca quinquemaculata*) and armyworms but total control was never reached for armyworms. The second season Bt was applied on a calendar schedule according to the previous years caterpillar activity dates, and total control was maintained. In general, Bt was very effective as a preventative insecticide against 1st and 2nd instar larva and less effective against large *Spodoptera frugiperda* caterpillars.

Virus infection

Virus infection can limit tomato production in Puerto Rico. In 2010, several plants were infected with virus mosaic and stunting symptoms, but samples were not taken for identification. In 2011, virus stunting was more wide spread and samples were sent out for identification. The University of Puerto Rico phytopatholgy lab at Juana Diaz concluded that the virus was a *potyvirus*, but no specific pathogen was identified. *Some potyviruses* with serologically related virions include *Potato Y virus, Tobacco etch virus, and the Peru mosaic virus* (Brunt et al., 1996). All these viruses are transmitted plant to plant by many different species of aphids (Davis et al., 2008). Aphids spread the virus when they move from crop to crop, not when they colonize a plant (Davis et al., 2008). It is common for a tomato plant to be infected by more than one *potyvirus* simultaneously, and also be infected by cucumber mosaic virus (Davis et al., 2008). These viruses can be transmitted by mechanical inoculation but not by seed (Davis et al., 2008). Intensive pruning and tying in the experiment could have accelerated virus inoculation to healthy plants.

All plants that displayed virus stunting before the first harvest were removed to reduce mechanical or insect vector transmission to healthy plants. ‘Roma’, our most productive variety in 2010, was the most rapidly overcome with virus symptoms in 2011.

‘Roma’ had an infection rate of 82% before the first harvest (Table 4). Other varieties rapidly infected were ‘Traveler 76’ (54%), ‘Eva Purple Ball’ (50%), ‘Ozark Pink’ (46%), and ‘Early Girl’ (46%). ‘Marion’ and ‘Ace 55’ had the lowest incidence of virus stunting before first harvest at 7%. By 100 DAT almost every plant showed signs of virus infection.

Comparative yields

Yield is determined by the interaction between the genetic make-up of a plant and its environment (Elings, 1999). Tomato yield is the product of fruit weight and the number of fruits per plant.

Yields of field-grown tomatoes usually range between 40 to 100 t/ha in Europe and North America (Heuvelink and Doris, 2005), mostly under conventionally managed systems with hybrid varieties. Kaffka et al. (2005) reported average marketable fruit yields of 63 t/ha for organically grown hybrid processing tomatoes in California. Juroszek et al. (2008) conducted a replicated trial at three different organic farms in Taiwan, using two hybrid processing tomato varieties. The marketable fruit yields were 22.2 t/ha in Sihun, 34.7 t/ha in Madou, and 55.1 t/ha in Shinhua. Higher yields in Shinhua were related to higher soil fertility, appropriate climate conditions, timely management skills, and the availability of *Bacillus thuringiensis (*Bt) for insect control (Juroszek et al., 2008).

In 1999 and 2000, Palada and Davis (2001) conducted a replicated organic tomato variety trial with 12 hybrids in the U.S Virgin Islands. They demonstrated that tomatoes could be successfully grown under organic management in the tropics and achieved yields comparable to the conventional sector (Palada and Davis, 2001). Our objective was to determine if open pollinated tomato cultivars could be successfully grown under organic management in the tropics. Both experiments occurred in two years and were planted on similar dates during the dry season. In the second season, both experiments suffered from large-scale mosaic virus infections.

In the organic variety trial in Lajas Puerto Rico, average projected marketable yield of 11 open pollinated cultivars and 3 hybrids was 38 (t/ha) in 2010 and 47 (t/ha) in 2011

(Tables 3 & 4). In comparison, average projected marketable yield of 12 hybrid varieties in the U.S Virgin Islands was 37 t/ha in 1999 and 27 t/ha in 2000. Yields were similar the first season of each experiment, but the second season in 2011, the Lajas trial produced 41% more marketable fruit then the Virgin Islands experiment.

In the 2010 and 2011 organic variety trials in Lajas, the open pollinated cultivars produced the highest actual yields both years, but their individual performance varied more than the hybrid controls. In the 2010 the open pollinated cultivars ‘Roma’ (72 t/ha) and ‘Neptune’ (57 t/ha) produced higher actual marketable yields than other cultivars (Table 3). The three hybrids controls, ‘BHN 444’ (56 t/ha), ‘Early Girl’ (45 t/ha), and ‘Celebrity’ (42 t/ha) followed closely behind the leaders. In 2011, the open pollinated cultivar ‘Flora Dade’ (46 t/ha) produced higher actual marketable yield than other cultivars. The two hybrids ‘BHN 444’ (44 t/ha), and ‘Celebrity’ (38 t/ha) followed closely behind the leader (Table 4). The three hybrid control cultivars ranked in the top 6 for actual marketable yield in both 2010 and 2011. Due to their heterozygous nature, hybrids can be expected to achieve greater yield stability through time and space than homozygous open pollinated cultivars (Allard and Bradshaw, 1964). Hybrids are genetically more diverse than open pollinated cultivars, which allows for greater adaption to changing climatic conditions. Yet, hybrids cannot be selectively bred by farmers and adapted to local conditions, which limits their use in sustainable organic agriculture. To achieve yield stability with open pollinated cultivars, farmers can plant a genetically diverse mix of locally adapted open pollinated cultivars. With greater genetic diversity, the farmer has greater insurance that at least some cultivars will have an adaptive advantage under shifting environmental conditions.

CONCLUSIONS

This experiment has shown that tomato can be successfully grown under an organic management system in Lajas, Puerto Rico during the dry season. In both 2010 and 2011, there were significant differences in yield and quality performance between cultivars. The hybrid control ‘Early Girl’ ranked highest on average in the two-year study in terms of taste, yield, and overall fruit appearance. ‘Early Girl’ appears to be well adapted to the organic farm-system in Lajas, Puerto Rico, and is recommended to organic growers. The open-pollinated tomato cultivars varied in performance from year to year, more than the hybrid controls. The open pollinated cultivars which ranked highest in the combined two year study in terms of taste, yield, and overall fruit appearance were ‘Roma’, ‘Homestead 24’, ‘Ozark Pink’, and ‘Traveler 76’. To attain yield stability with these or other open pollinated tomato cultivars, farmers can consider planting a genetically diverse mix of cultivars at each planting. This could help increase the adaptive capacity and overall performance of the tomato farm system as environmental conditions change.

The objective of this trial was to identify cultivars which were well adapted to organic management in Puerto Rico. Superior performing cultivars were ranked according to taste, yield and overall fruit appearance. ‘Early Girl’, ‘Ozark Pink’, ‘Homestead 24’, and ‘Traveler 76’ were among the top performers. Future organic tomato variety trials will need to identify other outstanding open pollinated tomato cultivars in order to optimize local organic production. Once identified, these superior performing cultivars can then be propagated for organic seed, or used in breeding programs.

APPENDIX A

Figure A-1. Experimental site of the 2010 and 2011 organic tomato variety trials, AES, Lajas, Puerto Rico. Picture taken 21 days after transplanting (DAT) in 2010.

Figure A-2. Experimental site of the 2010 and 2011 organic tomato variety trials, AES, Lajas, Puerto Rico. Picture taken 76 DAT in 2010.

Figure A-3. Tomato cultivars of the 2010 and 2011 organic variety trials.

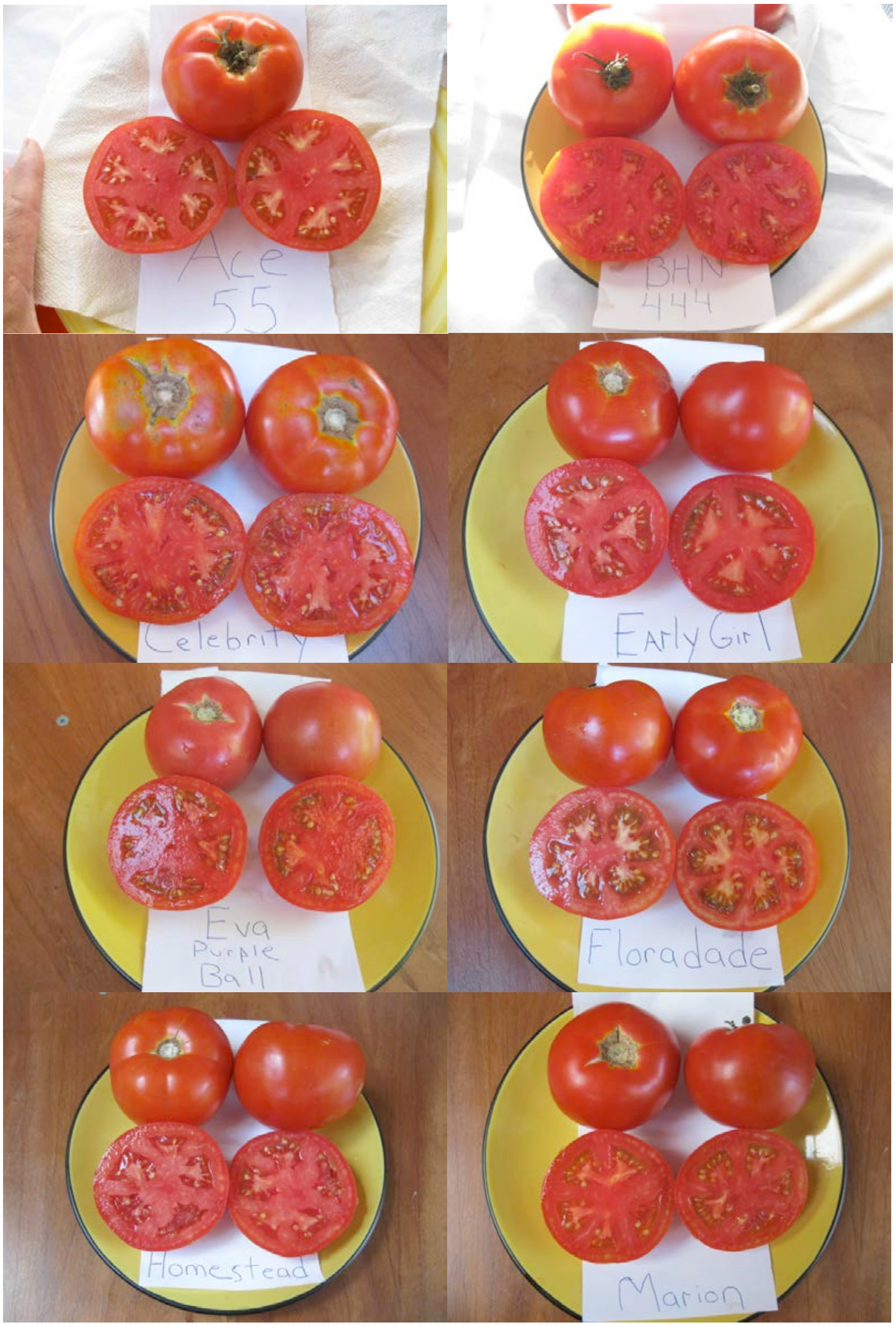

Figure A-3 continued.

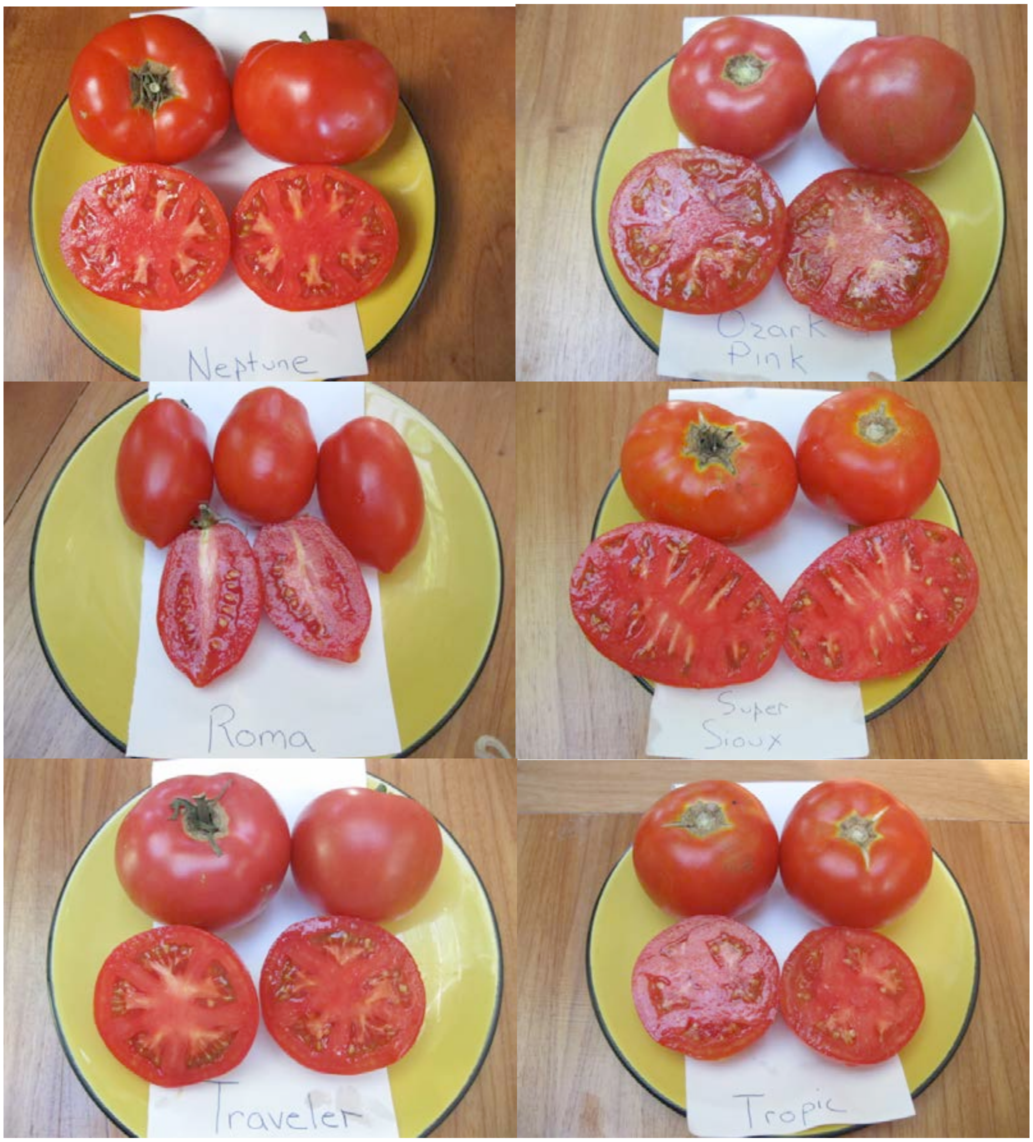

Figure A-4. Randomized complete block design, 2010 organic tomato variety trial, AES, Lajas, Puerto Rico. Plots consisted of seven plants each. There were 14 varieties and 4 replications. Plot dimensions are 1.8 m wide x 4.3 m long. Tomato plants were spaced 0.6 m apart.

FARMSCAPE	GRASS PATH 7'	Rep.1	GRASS PATH	Rep.2	GRASS PATH	Rep.3	GRASS PATH	Rep.4	GRASS PATH	FARMSCAPE
		114:7d Home		201:5i Eva		314:9d Neptune		401:4i Early		
		113:2d BHN		202:10i Ozark		313:7d Home		402:9d Neptune		
		112:6d Flora		203:8i Marion		312:11d Roma		403:7d Home		
		111:8i Marion		204:4i Early		311:6d Flora		404:11d Roma		
		110:12i Super		205:9d Neptune		310:3d Celeb		405:10i Ozark		
		109:9d Neptune		206:12i Super		309:12i Super		406:1d Ace 55		
		108:5i Eva		207:13i Traveler		308:8i Marion		407:3d Celeb		
		107:10i Ozark		208:6d Flora		307:4i Early		408:13i Traveler		
		106:4i Early		209:7d Home		306:5i Eva		409:5i Eva		
		105:1d Ace 55		210:14i Tropic		305:14i Tropic		410:8i Marion		
		104:14i Tropic		211:11d Roma		304:13i Traveler		411:2d BHN		
		103:3d Celeb		212:3d Celeb		303:10i Ozark		412:14i Tropic		
		102:13i Traveler		213:1d Ace 55		302:2d BHN		413:12i Super		
		101:11d Roma		214:2d BHN		301:1d Ace 5		414:6d Flora		

Figure A-5. Randomized complete block design, 2011 organic tomato variety trial, AES Lajas, Puerto Rico. Plots consisted of seven plants each. There were 14 varieties and 4 replications. Plot dimensions were 1.8 m wide x 4.3 m long. Tomato plants were spaced 0.6 m apart.

FARMSCAPE	GRASS PATH 7’		GRASS PATH		GRASS PATH		GRASS PATH		GRASS PATH	FARMSCAPE
		114:3d Celeb		201:6d Flora		314:5i Eva		401:14i Tropic		
		113:5i Eva		202:3d Celeb		313:4i Early		402:13i Traveler		
		112:6d Flora		203:9d Neptune		312:14i Tropic		403:10i Ozark		
		111:4i Early		204:10i Ozark		311:8i Marion		404:11d Roma		
		110:11d Roma		205:2d BHN		310:12i Super		405:8i Marion		
		109:9d Neptune		206:13i Traveler		309:1d Ace 55		406:3d Celeb		
		108:7d Home		207:8i Marion		308:3d Celeb		407:2d BHN		
		107:2d BHN		208:14i Tropic		307:9d Neptune		408:1d Ace 55		
		106:13i Traveler		209:12i Super		306:11d Roma		409:12i Super		
		105:8i Marion		210:4i Early		305:6d Flora		410:7d Home		
		104:10i Ozark		211:11d Roma		304:10i Ozark		411:5i Eva		
		103:14i Tropic		212:1d Ace 55		303:7d Home		412:4i Early		
		102:12i Super		213:5i Eva		302:13i Traveler		413:9d Neptune		
		101:1d Ace 55		214:7d Home		301:2d BHN		414:6d Flora		
		Rep.1		Rep.2		Rep.3		Rep.4		

Figure A-6. Marketable fruits harvested by plot, 2010/2011 organic tomato variety trials, AES, Lajas, Puerto Rico.

Figure A-7. Consumer preference survey, 2010 organic tomato variety trial, AES, Lajas, Puerto Rico.

Figure A-8. Consumer preference survey.

Overall Fruit Appearance

	Dislike very much	Dislike	Average	Like	Like very much	
Variety	1	2	3	4	5	Comments
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

Fruit Taste

	Dislike very much	Dislike	Average	Like	Like very much	
Variety	1	2	3	4	5	Comments
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

APPENDIX B

Table B-1. Monthly climatic data recorded at the NOAA substation, Lajas, Puerto Rico (latitude 18° 01’59” N, longitude 67°04’20”, and elevation 27 meters).

Substation 30 year Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum temperature (°C, & °F)	15.9°C 60.6°F	16.2 61.1	16.7 62.1	18.1 64.5	19.9 67.8	20.7 69.3	20.5 68.9	20.5 68.9	20.5 68.9	20.4 68.8	18.9 66.1	16.9 62.5
Mean temperature (°C, & °F)	23.2°C 73.7°F	23.3 73.9	23.7 74.7	24.7 76.4	25.9 78.6	26.7 80.1	26.8 80.2	27.3 81.1	26.6 79.9	26.3 79.3	25.3 77.5	23.9 75.0
Maximum temperature (°C & °F)	30.4°C 86.7°F	30.3 86.6	30.7 87.3	31.3 88.3	31.8 89.3	32.7 90.8	33.0 91.4	32.9 91.2	32.7 90.8	32.1 89.8	31.6 88.9	30.8 87.4
Monthly precipitation (cm & in.)	5.0cm 1.96in	5.4 2.12	5.1 1.99	7.0 2.74	10.5 4.15	6.9 2.71	6.8 2.66	14.5 5.69	16.6 6.54	17.3 6.8	13.6 5.36	5.8 2.29

(Source: http://www.climate-charts.com/USA-Stations/PR/PR665097.php)

Table B-2. Soil analysis results for the organic tomato variety trial, Agricultural Experiment Station, Lajas, Puerto Rico. (Reported 10/2009)

Parameters	Values	Status
% Organic matter	2.4	
ENR (lbs./A)	92	Medium
P1 Weak Bray (ppm)	1	Very Low
P1 Strong Bray (ppm)	5	Very Low
Potassium (ppm)	118 (2% saturated)	Very High
Magnesium (ppm)	559 (31% saturated)	Very High
Calcium (ppm)	1932 (65% saturated)	Very High
Sodium (ppm)	32 (0.9% saturated)	Low
Soil pH	8.2	Very High
C.E.C meq/100g	14.8	
Hydrogen meq/100g	0.0	
Sulfur (ppm)	18	Medium
Zinc	1	Very Low
Manganese (ppm)	28	High
Iron (ppm)	7	Medium
Copper (ppm)	11	Very High
Boron (ppm)	2	High
Soluble Salts mmhos/cm	0.18	Low

Table B-3. Tomato varieties selected for the tropical organic variety trial at the Lajas Experiment Station, Puerto Rico.

Variety (Source)*	Cultivar Type (OP/F1)**	Days to Maturity	Heat Tolerance	Disease Resistance*** Fruit Disorders****	Growth Habit	Average weight
1. Ace 55 (V)	OP	75	Yes	Fw1, Vw	Determinate	224 g
2. BHN 444 (T.G.S.)	F1	75	Yes	Fw1, Fw2, Tswv, Vw	Determinate	224 g
3. Celebrity (T.G.S.)	F1	70	Widely Adapted	An, Fw1, Fw2, Gls, Rkn, Tmv, Vw,	Determinate	224 g
4. Early Girl (T.G.S.)	F1	52	Widely Adapted	Fw1, Fw2, Vw	Indeterminate	140 g
5. Eva Purple Ball (S.E.S.)	OP	78	Yes	Eb, Lb, ber, cr, cf	Indeterminate	140 g
6. Flora Dade (V)	OP	78	Yes	Fw1, Fw2, Gls, Vw	Determinate	196 g
7. Homestead 24 (S.E.S.)	OP	80	Yes	Asc, Fw1 cf, cr	Determinate	224 g
8. Marion (T.G.S.)	OP	78	Yes	Bs, Fw1, Gls	Indeterminate	168 g
9. Neptune (S.E.S.)	OP	67	Yes	Bw, Fw1, Fw2, Gls, Vw1	Determinate	140 g
10.Ozark Pink (S.E.S.)	OP	65	Yes	Fw1, Vw ber, cr	Indeterminate	196 g
11. Roma (S.E.S.)	OP	75	Widely Adapted	Bs, Fw1, Vw	Determinate	112 g
12. Super Sioux (V)	OP	70	Yes	Vw (made Sioux super)	Indeterminate	140 g
13. Traveler 76 (V)	OP	76	Yes	Fw1, Vw cr, drought tolerance	Indeterminate	224 g
14. Tropic (S.E.S.)	OP	80	Yes	Asc, Clm, Eb, Fw1, Gls, Rkn, Tmv1, Tmv4,Vw; cr, gw, sun	Indeterminate	227 g

*Source: Southern Exposure Seeds (S.E.S.), Victory Seeds (V), Tomato Growers Supply (T.G.S.)
**OP = open pollinated; F1 = hybrid
***Disease abbreviations (From S.E.S catalog): Asc = *Alternaria* stem canker, An= *Anthracnose,* Bs = bacterial spot, Bw = bacterial wilt, Clm = *Cladosporium*, Eb = early blight *(Alternaria),* Fw1 = *Fusarium* wilt race 1, Fw2 = Fusarium wilt race 2, Gls = gray leaf spot, Lb = late blight, Rkn = root knot nematode, Tmv = tobacco mosaic virus, Tswv = tomato spotted wilt virus, Vw = *Verticillium* wilt. ****Fruit disorders (From S.E.S catalog): ber = blossom end rot, cf = catfacing, cr = crack resistance, gw = gray wall, sun = sun scald

Table B-4. Spray schedule with OMRI approved products during the 2010 organic tomato variety trial at the Lajas Agricultural Experiment Station.

DAT*	Product Applied
2	Agree (Bt) 1% for armyworms/cutworms
6	Agree 1%
8	Trilogy 1% (neem oil) insecticide/ fungicide/ bactericide
9	Agree 1%
12	Garlic Barrier 5% insecticide/ fungicide
14	Biolink liquid fertilizer 2% (1-5-5)
16	Ecotrol 0.5% (rosemary oil) for whiteflies
19	Biolink liquid micronutrient fertilizer (2%-Fe, 2%-Mn, 3%-Zn)
22	Trilogy 1%
29	Biolink liquid fertilizer 2% (1-5-5)
33	Trilogy 1%
36	Dipel (Bt) 1%
44	Biolink liquid fertilizer 2% (1-5-5)
48	Biolink liquid micronutrient fertilizer (2%-Fe, 2%-Mn, 3%-Zn)
49	Ecotrol 2%
56	Dipel 1% + Trilogy 1%
62	Dipel 1% + Trilogy 1%
65	Dipel 2% + Trilogy 2%
70	Aza-Direct 1% (Azadirachtin-active ingredient in neem seed kernels) for white flies
76	Agree 1% + Aza-Direct 1%
83	Biolink liquid fertilizer 2% (1-5-5)
85	Alaskan fish emulsion 1%
92	Alaskan fish emulsion 1% + Trilogy 1%

*DAT = days after transplanting to the field.

Table B-5. Spray Schedule with OMRI approved products during the 2011 organic tomato variety trial at the Lajas Agricultural Experiment Station.

DAT*	Product Applied
1	Dipel (Bt) 1% for caterpillars + Trilogy 1% for fungicide/insecticide
4	Milstop 1% for fungicide
8	Trilogy 1% + Dipel 1%
11	Oxidate 1% for fungicide + Trilogy 2%
15	Oxidate 1% + Trilogy 2%
18	Bioflora liquid fertilizer (2-1-1) 4% + Trilogy 2%
22	Oxidate 1% + Trilogy 1%
25	Bioflora liquid fertilizer (2-1-1) 6% + Sporan EC (rosemary oil) 1% knock-down insecticide especially for white flies
29	Garlic Barrier 3% for fungicide/insecticide + Trilogy 2%
32	Oxidate 1% + Sporan EC 1% + Trilogy 1%
36	Trilogy 0.75% + Sporan EC 0.75% + Garlic 0.4%, + Milstop 1%
39	Trilogy 0.75% + Sporan EC 0.75%, + Garlic 0.5% + Milstop 1%
41	Bioflora liquid fertilizer (2-1-1) 4% + Dipel 1%
43	Bioflora liquid ferilizer (2-1-1) 4% + Dipel 2%
48	Trilogy 1%, + Sporan EC 0.75%, + Dipel 2%, + NuFilm 0.25% (sticker/spreader)
52	Dipel 1% + Milstop 1% + Trilogy 1% + NuFilm 0.25%
56	Dipel 1% + Sporan EC 1% + Trilogy 1% + NuFilm 0.25%
63	Dipel 1 % + Aza-Direct 1% + Oxidate 1%
76	Dipel 1%
82	Bioflora liquid fertilizer (2-1-1) 2% + Garlic Barrier 2% + Sporan EC 1%
91	Garlic Barrier 2% + Sporan EC 1% + oxidate 1% + NuFilm 0.25%

*DAT = days after transplanting to the field.

REFERENCES

Adam, K. 2005. Seed production and variety development for organic systems. Appropriate Technology Transfer Rural Areas (ATTRA). Web. 5 July 2011. http://www.attra.ncat.org/attra-pub/seed_variety.html

Allard, R., and Bradshaw, A. 1964. Implications of genotype-environment interactions in applied plant breeding. Crop Science 4:503-508.

Almodóvar, A., and Alamo, I. 1999. Trends in the production and export of winter tomato in Puerto Rico and the United States before and after NAFTA during 1990-1997. Proceedings of the 35th annual meeting, Caribbean Food Crops Society, Castries, St.Lucia, 25-31 July. p.31-38.

Asgedom, S., Struik, P., Heuvelink, E., Araia, W. 2011. Opportunities and constraints of tomato production in Eritrea. African Journal of Agricultural Research 6(4):956-967.

Bachmann, J. 2008. Farmers' Markets: Marketing and business guide. Appropriate Technology Transfer Rural Areas (ATTRA). Web. 13 July 2011. https://attra.ncat.org/attra-pub/PDF/farmmarket.pdf

Brunt, A., Crabtree, K., Dallwitz, J., Gibbs, J., Watson, L., Zurcher, J. 1996. Plant viruses online: Descriptions and lists from the VIDE database. Version: 20th. Web. 19 July 2011. http://www.biology.anu.edu.au/Groups/MES/vide/

Cheryld, L., Emmons, W., Scott, W. 1997. Environmental and physiological effects on cuticle cracking in tomato. J. Am. Soc. Hort. Sci. 122:797-801.

Chaurasia, S., Singh, K., Rai, M. 2005. Effect of foliar application of water soluble fertilizers on growth, yield, and quality of tomato (*Lycopersicon esculentum* L.). Sri Lankan J. Agric. Sci. 42:66-70.

Colberg-Rivera, O., Vélez-Colón, C., Alamo-González, C., Chao de Báez, C. 1996. Fresh market tomato cultivar trials at two locations. J. Agric.Univ. P.R. 80(3):207-210

Colley, M., Dillon, M. 2004. The next great challenge: Breeding seed for organic systems. Organic Farming Research Foundation. Information Bulletin Winter No. 13. Web. 5 July 2011 http://www.seedalliance.org/uploads/pdf/OrganicBreedingChallenge.pdf

Colley, M., Myers, J. 2007. On-farm variety trials: A guide for organic vegetable, herb, and flower producers. Organic Seed Alliance. June. Web. 17 April 2011 http://www.seedalliance.org/uploads/publications/OVT_Guide.pdf

Cox, B. 2011. Training systems and pruning in organic tomato production. Reviewed for compliance with National Organic Program regulations. Browse by tag: eOrganic 2620. Web. 10 June 2011.http://www.extension.org/pages/18647/training-systems-pruning-in-organic-tomato-production

Dalpe, Y., Monreal, M. 2003. Arbuscular mycorrhizal inoculum to support sustainable cropping systems. Web. 10 February 2010. http://www.org/sub/cm/review/2004/amfungi/Dalpe.pdf

Davis, R., Miyao, G., Subbarao, K., Stapleton, J. 2008. UC IPM pest Management guidelines: Tomato mosaic diseases caused by *potyviruses*. UC ANR publication 3470. Web. 19 July 2011. http://www.ipm.ucdavis.edu/PMG/r783102611.html

Departamento de Agricultura de Puerto Rico. 2010. Ingreso Bruto Agricola año fiscal 2008-2009. Oficina de Estadisticas Agricolas. p.19

Dillon, M., Hubbard, K. 2011. State of organic seed. Organic Seed Alliance. February. Web. 8 July 2011. http://seedalliance.org/uploads/publications/SOS_2011_Report.pdf

Diver, S., Kuepper, G., Born, H. 1999. Organic tomato production. Horticulture production guide. Appropriate Technology Transfer for Rural Areas (ATTRA). March. Web. 13 April 2009. http//:www.attra.org/attra-pub/tomato.html

Dufour, R. 2000. Farmscaping to enhance biological control. Appropriate Technology Transfer for Rural Areas (ATTRA). December. Web. 13 December 2010. http//:www.attra.ncat.org/attra-pub/farmscape.html

Elings, A. 1999. Some theory and practice of the participatory variety selection and plant breeding. Community biodiversity development and conservation program. Web. 25 July 2011 http//:www.cdbcprogram.org/final/firstphase/reports/acr_reader/participatory_variety_selection.pdf

Federal Register. 2000. National Organic Program Rule. Vol.65 No.246 December 21. p.13. Web. 11 September 2011. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5087165

Fornaris, G., Guadalupe, R., Beauchamp de Caloni, I., Chao de Báez, C. 1991. Yield and acceptability of eight fresh market tomato cultivars. J. Agric. Univ. P.R. 75(1):93-95.

Fornaris, G. 2007. Variety selection. Conjunto tecnologico para tomate de ensalada. Publication 166, Agricultural Experiment Station, University of Puerto Rico. p.15-19.

Fornaris, G., Martínez, S., Rosa, E., Cabrera, I. 2009. Proceso de evaluación en dos fases de cultivares de tomate de ensalada (*Solanum lycopersicum* L.) de 2003 a 2007. Informe del Proyecto H-094-S (unpublished)

Gaskell, M., Smith, R., Mitchell, J., Koike, S., Fouche, C., Hartz, T., Horwath, W., Jackson, L. 2007. Soil fertility management for organic crops. University of California. Division of Agriculture and Natural Resources. Publication 7249. Web. 29 August 2011. http:ucanr.org/freepubs/doc/7249.pdf

Ge, J. 2006. Simulation modeling and benefit-cost sensitivity analysis for technology adoption on Puerto Rico-United States tomato supply chain. M.S thesis. University of Florida, Gainesville.

Gepts, P. 2006. Plant genetic resources conservation and utilization: the accomplishment and future of a societal insurance policy. Crop Sci. 46:2278-2292.

Gerber, J. 1979. Staking and training tomato plants. College of the Virgin Islands Cooperative Extension Service. Gardeners Factsheet. March No. 7. Web. 15 July 2011. http://www.guamsustainableag.org/knowingyourcrops/gf7%20(8).pdf

Govardhan, S. 2007. Food security in Puerto Rico. Web. 15 September 2011. http://organicfarm.net/Article_food_security_in_puerto_rico.htm

Guptill, A., 2004. Barriers to organic agriculture in Puerto Rico under U.S. colonialism. Web. 14 August 2011. http://indymediapr.org/news/2004/09/4716.php

Heuvelink, E., Doris, M. 2005. Crop growth and yield. In: Heuvelink, E. (ed.) Tomatoes. Crop production science in horticulture 13, Cromwell Press, Trowbride. p.85-114.

Hill, H., 2008. Food miles: Background and marketing. A publication of ATTRA. Web. 13 July 2011. http://kirikiva.com/PDF/Foodmiles.pdf

Jacobsen, I., Abbott, K., Robson, A. 1992. External hyphae of vesicular arbuscular mycorrhizal fungi associated with *Trofoluim suterraneum* L. Spread of hyphae and phosphorous inflow into roots. New Phytol. 120:371-380.

Jones, B. 1999. Tomato plant culture. In the field, greenhouse, and home garden. CRC Press, Boca Raton, FL.

Juroszek, P., Ma, Chin-Hua., Tsai, Hsing-Hua., Wu, Deng-Lin., Palada, M. 2007. Utilisation of diversity in land use systems: Sustainable and organic approaches to meet human needs. Organic farming research at AVRDC- The World Vegetable Center. Tropentag, October 9-11 2007, Witzenhausen, Germany.

Juroszek, P., Ledesma, D., Ma, H., Yang, Y., Lumpkin, M., Lin, C., Tsai, H., Wu, L., Hanson, M., Palada, C. 2008. Plant vigor and yields of organically and conventionally grown tomato crops in Taiwan. Acta Hortic. 767:257-266.

Kaffka, S., Bryant, D., Denison, F. 2005. Comparisons of organic and conventional maize and tomato cropping systems from a long-term experiment in California. Web. 11 July 2011. http://orgprints.org/4384

Lammerts van Bueren, E. 2002. Organic plant breeding and propagation: Concepts and strategies. PhD thesis, Wageningen University, the Netherlands.

Lammerts van Bueren, E. 2003. Challenging new concepts and strategies for organic plant breeding and propagation. Eucarpia Leafy Vegetables. p.1-6. Web. 29 June 2011. http://www.leafyvegetables.nl/downloads/04_017-022_Lammerts.pdf

Lammerts van Bueren, E., Hulscher, M., Haring, M., Jongerden, J., Mansvelt, J., Nijs, A., Ruivenkamp, G. 1999. Sustainable organic plant breeding. Final report: A vision, choices, consequences and steps. Louis Bolk Instituut, Netherlands. Web. 27 July 2011. http://orgprints.org/1419/

Lammerts van Bueren, E., Jones, S., Tamm, L., Murphy, K., Myers, J., Leifert, C., Messmer, M. 2010. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. Njas – Wageningen Journal Life Science. p.1-13. Web. 6 July 2011. http://www.sciencedirect.com/science/article/pii/S157352140000014X

Lammerts van Bueren, E., Struik, P., Jacobsen, E. 2002. Ecological concepts in organic farming and their consequences for an organic crop ideotype. Netherlands Journal of Agricultural Science 50. p.1-26. Web. 16 June 2011. http://library.wur.nl/ojs/index.php/njas/articles/downloads/401/119

Mendum, R., Glenna, L. 2010.Socioeconomic obstacles to establishing a participatory plant breeding program for organic growers in the United States. Sustainability (2):73-91. Web. 19 August. 2011. http://www.mdpi.com/journal/sustainability

Murphy, K., Campbell, K., Lyon, S., Jones, S. 2007. Evidence of varietal adaptation to organic farming systems. Field Crops Research (102):172-177.

National Cooperative Soil Survey USA, 2006. Fraternidad series. Web. 15 January 2010. http://%20FRATERNIDAD%20Series.webarchive

O'Connell, S. 2008. Grafted tomato performance in organic production systems: Nutrient uptake, plant growth, and fruit yield. Masters thesis, North Carolina State University.

Pantoja, A., Cabrera, I., Bastidas, H. 1999. Biocontrol news and information. 20(4):113-114.

Pagaling, S., Holmer, R., Acosta, J., Schnitzler, W. 1999. First results of tomato (*Lycopersicon esculentum* Miller) variety trials under tropical lowland conditions. Paper presented during the 11th NOMCARRD Regional Symposium on Research and Development Highlights, July 28-29. Claveria, Misarnis Oriental, Philippines.

Palada, M., Davis, A. 2001. Yield performance of tomato cultivars grown under organic management system. Proceedings of the Caribbean Food Crops Society 37:154-160.

Palada, M., Roan, Y., Black, L. 2003. Rain shelters for tomato production in the hot-wet season. International Cooperators' Guide. AVRDC pub # 03-552. November. Web. 21 August 2011. http://www.avrdc.org/LC/tomato/shelter.pdf

Peet, M., Bartholemew, M. 1996. Effect of night temperature on pollen characteristics, growth, and fruit set in tomato. J. Amer. Soc. Hort. Sci. 121(3):514-519.

Peet, M., Willitis, H. 1995. Role of excess water in tomato fruit cracking. HortScience 30:65-68.

Pérez-Alegría, L., Beinroth, F., Hansen, J., Jones,. J. 1997. Assessment of the environmental impact and sustainability of agricultural production systems in southern Puerto Rico. A presentation of the Regional Congress of AIDIS for North America and the Caribbean, San Juan, 8-12 June 1997.

Premsekhar, M., Rajashree, V. 2009. Performance of hybrid tomato as influenced by foliar feeding of water soluble fertilizers. American-Eurasian Journal of Sustainable Agriculture 3(1):33-36.

Pretty, J., 2001. Some benefits and drawbacks of local food systems. Briefing note for TVU/Sustain Agrifood Network. November. Web. 10 July 2011. http://www.sustainweb.org/pdf/afn_m1_p2.pdf

Ryan, F. 2011. A new dawn for Puerto Rico's food industry. Web. 11 July 2011. http://www.christiansen-portela.com/blog/2011/07/the-future-of-food/

Sato, S., Peet, M., Thomas, J. 2001. Physiological factors limit fruit set tomato (*Lycopersicon esculentum* Mill.) under chronic, mild heat stress. Plant, Cell and Environment 23:719-726.

Schonbeck, M., Damian, K., Dawling, P., Maloney, C. 2006. Tomatoes: Organic production in Virginia. Virginia Association for Biological Farming Information Sheet. No. 5-06. Web. 14 November 2009. http://www.vabf.org/docman/information-sheets/tomatoes-organic-production-virginia/view

Securities and Exchange Commission. 1996. Calgene Inc. Form 10-K. June. Web. 20 June 2011. http://www.secinfo.com/durdh.96.htm

Sullivan, P. 2004. Sustainable soil management. Soil systems guide. Appropriate Technology Transfer for Rural Areas (ATTRA). May. p.22. Web. 17 December 2010. http://www.soilandhealth.org/01aglibrary/010117attrasoilmanual/010117attra.html

Tomato Magazine. 2005. Florida tomato conference 2004-2005 described as a roller coaster year. October. Web. 15 June 2011. http://www.columbiapublications.com/tomatomagazine/october2005/floridaconference.htm

Tomato world production statistics. 2005. Web. 10 June 2011. http://www.growtomatoes.com/world_production_statistics.htm

Update 10 brix tomato challenge, 2010. Web. 15 October 2011. The beautiful taste. http://jonrowley.com/2010/09/24/tomatochallengeupdate/

USDA. 1999. Sunn hemp: A cover crop for southern and tropical farming systems. Soil quality- Agronomy technical note. No. 10. Web. August 13 2011. http://soils.usda.gov/sqi/management/files/sq_atn_10.pdf

Valenzuela, H., Smith, H. 2002. Cowpea. Cooperative Extension Service. College of Tropical Agriculture and Human Resources (CTAHR). University of Hawaii at Mañoa. August. SA-GM-6. Web. 13 August 2011. http://www.uky.edu/Ag/CDBREC/introsheets/southernpea.pdf

Vetiver Solutions Blog. 2010. Vetiver as windbreaker at Gargiulo Puerto Rico. Web. 5 July 2011. http://www.vetiversolutions.info Rico./2010/01/vetiver-as-windbreak-gargiulo-puerto.htm

Wessel-Beaver, L., Fornaris, G., Armstrong, A., Caraballo, E. 1990. Producción de tomate fuera de época. In*:* Memorias del foro técnico Cultivo, Producción y Elaboración de Tomate. Estación Experimental Agricola, Universidad de Puerto Rico. p.13-17.