2. Chapter II. Article I: How does increased vegetable varietal choice influence coffee farmers' on-farm diversification strategies in the face of changing climate conditions?

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Abstract

Crop diversification strategies are thought to be promising for Central American coffee farmers looking for solutions to confront rapidly changing climate conditions. Vegetable crops hold potential for diversification of coffee and other production systems because of their high potential for income and nutrition security. However, limited seed choice may lead to poor adaptation and eventually become a constraint for introducing these crops. We anticipate that with an increase in varietal choice of vegetable crops, farmers can make better choices when diversifying their farms, taking into consideration environmental and management conditions that lead toward more sustainable and intensified production. This study employs participatory evaluation with eight coffee farmers in Turrialba, Costa Rica, at two altitudes and under two different types of management (conventional and organic), as well as morphological characterization and farmer evaluation of a diverse array of tomato and sweet pepper accessions and varieties (AVRDC varieties, CATIE accessions and commercial varieties) to determine whether increased varietal choice improves on-farm diversification strategies in the face of climate change. These accessions and varieties came from the CATIE genebank and the AVRDC breeding program, and their performance was compared to available commercial varieties. Farmers' scores from the participatory evaluation demonstrate that farmers identify a wide range of successful AVRDC varieties and CATIE accessions that score better for farmer-preferred traits when compared with the standard commercial varieties. Both altitude and type of management influence farmers' varietal preferences, illustrating the importance of increased varietal choice for coffee farmers growing in diverse environments. Characterization data also shows significant interactions between variety, altitude and type of management. A comparison of the most successful varieties defined by farmers and the most successful varieties according to characterization data demonstrates that farmers often indicate different varieties that are different from those indicated in agronomic evaluation studies as having the most potential to diversify farms. Without using participatory methods to include farmers' preferences in varietal selection, varieties may be promoted that appear more satisfactory but are actually not preferred by the farmers themselves. Farmers' opinions of the present study illustrate that the current participatory evaluation of increased varieties was an effective tool to help identify several new varieties that have high potential for diversifying farms.

Key words: agrobiodiversity, tomato, *Solanum*, sweet pepper, *Capsicum*, increased varietal choice, coffee, climate change, diversification, genetic diversity, genebank accession, improved variety

2.1 Introduction

With constantly unstable and changing climate conditions, relying on a range of crops as opposed to just one or a few crops allows farmers to stabilize income and maintain a reliable food supply (Tshewang *et al.* 2003;Almekinders *et al.* 2007;Lin 2011;Jacobsen *et al.* 2015). Therefore, crop diversification has been identified as a vital component in adaptation of agricultural systems to climate change (Wood and Lenne 1997;Zhu *et al.* 2000;Kirschenmann 2007;Mercer and Perales 2010;Lin 2011;Thomas *et al.* 2015). In Central America, diversification has become a crucial component for adapting coffee systems and reducing the reliance of farm-family income and food security only on selling coffee beans (Bacon 2005;Caswell *et al.* 2012;Morris *et al.* 2013). Introducing new crops to coffee farms, such as vegetable crops, increases the functional diversity of the system and therefore broadens the environmental niche so that multiple crops can perform well within the same system (Ebert 2014). It also offers opportunities to reduce market risks by having alternative cash crops when coffee prices are low.

Considering these benefits, many diversification projects have started in coffee-based systems as well as other production systems in Central America (Caswell *et al.* 2012). However, seed is often acquired without considering varietal diversity that would enable selecting materials adapted to specific conditions. We anticipated that limited seed choices could lead to poor adaptation on some farms and eventually discourage farmers from diversifying. This happens when available varieties do not produce well under a wide range of specific management or environmental conditions, such as, for example, in mountainous areas.

Genebank collections contain a broad diversity of potentially interesting materials for crop diversification. This diversity is a valuable source for breeding varieties that can be offered to farmers. These materials could also be provided directly to farmers for evaluation to reduce time from genebank to farmer and to make a better use of the diversity maintained in these collections that could respond to farmers' preferences for specific traits and materials (Bioversity International 2014).

Farmers and farmer organizations are increasingly interested in exploring the full potential of these varieties for income and food and nutrition security. Specific mechanisms have been successfully created to facilitate farmers' use and evaluation of diverse plant genetic material, including participatory varietal selection (PVS) (Witcombe *et al.* 1996;Friis-Hansen and Sthapit 2000;Scheldeman *et al.* 2001;Almekinders *et al.* 2007;Ceccarelli and Grando 2007;Danial *et al.* 2007;Ciancaleoni *et al.* 2014). Evaluation and characterization data on modern varieties and traditional genebank varieties collected from on-farm PVS trials allows farmers and researchers to make a targeted selection of diverse genetic material tailored to local conditions (Witcombe 2003;Lin 2011).

The aim of this study is to understand the role of increased varietal choice and PVS in motivating producers to adopt new crops for diversification activities on their farms. The following specific research questions will be addressed:

- To what extent are coffee producers interested in improved varieties and genebank accessions for diversification of their farms?
- How do farmers' preferences for varieties related to their desired traits change at different altitudes or under different types of management (organic versus conventional)?
- How does increased varietal supply increase crop performance according to traits of interest at different altitudes or under different types of management (organic versus conventional)?
- What is the role of participatory evaluation and participatory varietal selection in helping farmers identify more interesting varieties for crop diversification?

We tested our questions through PVS of sweet pepper and tomato accessions and varieties with four conventional and four organic coffee farmers in Turrialba, Costa Rica, at two different altitudes.

2.2 Materials and methods

2.2.1 Study area

The farms in the study are located in the canton of Turrialba in the province of Cartago, Costa Rica. The altitude of Turrialba varies between 600 and 1,400 meters above sea level. Turrialba covers 1,642 square kilometers and is located 45 kilometers southeast of San Jose. The average precipitation of the canton is 2,600 millimeters per year, with an average temperature of 21.5 degrees Celsius (ICAFE 2014).

In recent years, variable climate conditions and other factors have negatively influenced coffee production in Turrialba. Coffee producers in Turrialba are located between 600 and 1,400 meters above sea level; however, the optimal altitude for coffee production has shifted from 1,200 to 1,600 meters (Baca *et al.* 2014). Climate changes have meant an increase in pest and disease incidence: in 2014, 100% of the coffee production area in Turrialba was affected by coffee rust, drastically affecting productivity in the region (ICAFE 2014). Due to these changing factors, coffee producers are searching for alternative crop options that will allow them to adapt to current and future changes.

2.2.2 Experimental design

Accessions and varieties of tomato and sweet pepper were planted during on-farm varietal trials conducted with eight farmers, out of the 14 initially interviewed. The trials were established as an unbalanced randomized block experiment, with altitude as the primary block. Four farms were located above 1,000 meters (high altitude), while four were located below 1,000 meters (low altitude). Farmer type was the secondary block. Four farmers used conventional management and four organic. Each farm represented a repetition and therefore there were no repetitions within the farms (see Table 4).

Table 4. Basic information on the eight farms included in the study

Producer	Farm location	Type of management*	Altitude (meters)	Latitude	Longitude
Carlos	Alto de Humo	C	1,000	9.79892	-80.73017236359613
Enrique	San Juan Sur	C	1,000	9.87341	-80.69169494176563
Daniel	San Juan Norte	O	1,120	9.896679	-80.6986603118575
Jorge	San Juan Sur	O	1,022	9.873113	-80.69277147539046
Benedicto	Pejibaye	C	675	9.813302	-80.69392105670536
Celso	Javillos	C	697	9.921817	-80.62121779216601
Rosa	Pejibaye	O	690	9.806132	-80.70649360440605
Edgar	Chitaria	O	760	9.927043	-80.58904680787752

Note: C = conventional management, O = organic management

2.2.3 Crop selection

Fourteen initial producers—seven conventional and seven organic—from 37 contacted current and ex coffee producers in Turrialba, Costa Rica, participated in initial interviews to select preferred crops for diversification from four horticultural crop options: squash, sweet pepper, hot pepper and tomato. These four crops were selected as options because CATIE's regional genebank maintains highly diverse collections of these crops, which are openly accessible under the Multilateral System (MLS) established through FAO's International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRAFA). These same farmers were also asked to define the most preferred traits for both tomato and sweet pepper.

2.2.4 Farmer profile

All farms in the study are between three and seven hectares. Six of the farmers are still primarily coffee farmers, while the other two have recently stopped producing coffee. The farmers that still have coffee are dedicated mostly to coffee, as it is the most time- and resource-consuming crop on the farms. All of the producers in the study are farmers looking for diversification alternatives due to the drastically low coffee prices and uncertainty associated with the crop.

All of the producers agree that diversification within the farm increases the economic and environmental resistance of the system. Every farm has already been diversified from coffee monocrops, principally with bananas, vegetables, aromatic herbs, legumes and activities such as animal husbandry and tourism. However, in most cases, the farmers that have diversified with vegetable crops have access only to commercially available hybrid varieties. Use of open-pollinated or heirloom varieties for diversification was of interest to every farmer in the study because these varieties are not regularly available, so any opportunity to work with them is attractive to the farmers. While most organic farmers expressed interest in using these types of varieties due to their positive effects on agrobiodiversity on the farm, both conventional and organic farmers expressed interest in using these materials to save and reproduce seed, which is not possible with the hybrid commercial varieties, leaving them dependent on local greenhouses each year.

2.2.5 Variety and accession selection

Improved, open-pollinated tomato and sweet pepper varieties from the World Vegetable Center (AVRDC) in Taiwan, heirloom variety accessions from the Tropical Agricultural and Higher Education Center (CATIE) genebank in Costa Rica and common commercial varieties available in the region were planted on each farm.

For tomato, the initial varieties selected included two AVRDC improved varieties, one commercial variety (JR) and eight accessions from CATIE's genebank. Many of CATIE's genebank collections consist largely of landrace and heirloom varieties. For sweet pepper, the initial varieties selected included two AVRDC varieties, 1 commercial variety (Natalie) and seven accessions from the CATIE genebank. Later on, two more sweet pepper varieties were planted, one commercial variety (4212) and one AVRDC improved variety. The commercial varieties selected were the most commonly used commercial varieties of tomato and sweet pepper in Turrialba, Costa Rica, at the time of the study.

Table 5. General information and passport data for the varieties and accessions used in the current study

Crop	Accession	Identifier	Genus	Species	Date introduced	Origin
Tom.	5515	CATIE select1	*Solanum*	*lycopersicum*	2/10/1976	Peru
Tom.	5640	CATIE select2	*Solanum*	*lycopersicum*	2/10/1976	Peru
Tom.	10596	CATIE select3	*Solanum*	*lycopersicum*	26/12/1979	Guatemala
Tom.	20485	CATIE select4	*Solanum*	*lycopersicum*	14/02/1995	Costa Rica
Tom.	20547	CATIE select5	*Solanum*	*lycopersicum*	14/02/1995	Costa Rica
Tom.	20553	CATIE random1	*Solanum*	*lycopersicum*	14/02/1995	Costa Rica
Tom.	17358	CATIE random2	*Solanum*	*lycopersicum*	14/07/1986	United States
Tom.	17330	CATIE random3	*Solanum*	*lycopersicum*	07/06/1986	Panama
Tom.	1426	AVRDC1	*Solanum*	*lycopersicum*	N/A	Taiwan
Tom.	1424	AVRDC2	*Solanum*	*lycopersicum*	N/A	Taiwan
Tom.	JR	Commercial1	*Solanum*	*lycopersicum*	N/A	N/A
Pepper	18757	CATIE select1	*Capsicum*	*annuum*	30/01/1990	Costa Rica

Pepper	15661	CATIE select2	*Capsicum*	*annuum*	1/12/1983	Guatemala
Pepper	17268	CATIE Select3	*Capsicum*	*baccatum*	3/3/1986	Guatemala
Pepper	9777	CATIE select4	*Capsicum*	*frutescens*	28/07/1979	Costa Rica
Pepper	17151	CATIE random1	*Capsicum*	*annuum*	19/12/1985	United States
Pepper	18660	CATIE random2	*Capsicum*	*annuum*	22/09/1989	Spain
Pepper	19259	CATIE random3	*Capsicum*	*annuum*	21/01/1992	Russia
Pepper	032170	AVRDC1	*Capsicum*	*annuum*	N/A	Taiwan
Pepper	1247	AVRDC2	*Capsicum*	*annuum*	N/A	Taiwan
Pepper	9814	AVRDC3	*Capsicum*	*annuum*	N/A	Taiwan
Pepper	Natalie	Commercial1	*Capsicum*	N/A	N/A	N/A
Pepper	4212	Commercial2	*Capsicum*	N/A	N/A	N/A

Accessions from CATIE's genebank were selected based on previously identified farmer-preferred traits. Preferred traits defined by the producers were translated into scientific descriptors so that the accessions could be filtered based on genebank descriptions. Explora used a weighted sum model to create a subset from which the final genebank accessions were selected. The initial subset was defined by weight (tomatoes with a weight of 250 grams or more), width of endocarp, number of days to flowering and color of pulp (in order from most important to least important). Five CATIE accessions were selected based on seed availability from the initial subset of 15 accessions generated by Explora. Additionally, three accessions were randomly selected as reference material from a randomly generated set of 100,000 genebank accessions. We were able to select three sweet pepper accessions manually because the CATIE genebank only maintains nine sweet pepper accessions. Four other accessions were selected at random as a reference.

2.2.6 Seedling development

Seeds of the CATIE accessions and AVRDC improved varieties were ordered using the Standard Material Transfer Agreement (SMTA) developed by the ITPGRFA. The commercial varieties were ordered from a local commercial nursery. Initially, the AVRDC variety and CATIE accession seedlings were germinated in a greenhouse at CATIE beginning in February 2015. Due to low survival rates, a second batch was germinated and developed by a commercial greenhouse in Cervantes, Costa Rica, in March 2015.

2.2.7 Transplant

Varieties were transplanted beginning in April 2015. Tomato and sweet pepper varieties were planted under roofs made of plastic bands put in place by the study. On each farm and for both crops, a buffer border row was planted on both sides of the study plot. The seedlings were planted with 40 cm between each seedling and 1 meter between each row. In each plot, fertilizer was applied at the time of planting. On conventional farms, a fungicide was also applied directly following the transplant.

2.2.8 Climate sensors

Climate sensors, iButtons, were installed at each farm at the beginning of the study. The iButtons measured temperature in degrees Celsius as well as relative humidity. Each sensor was placed in an apparatus made according to an instruction manual written by Bioversity International (Mittra *et al.* 2013).

2.2.9 Farmer management

Farmer management was homogenized among conventional farms as well as organic farms through development of a common management and fertilization guide for each of the two management types (Appendix 1). All conventional farmers received the same conventional inputs and all organic farmers, the same organic inputs. After the initial inputs were given to the farmers, other inputs were ordered and given as-needed to combat farm-specific issues that occurred during the study (Appendix 2). All farmers applied the same cultural practices to the study plants (Appendix 3).

Management indicators were developed, taking into consideration the most important management aspects defined by the study, to score the management of each farmer, using a Likert scale. These management aspects included: weed management, plant support, independent management by farmer, application of provided inputs, water drainage, trimming, removal of infected plant parts from plant, removal of infected plant parts from study area and row height of planting rows (Appendix 4). Average scores for each management indicator of interest in general, as well as pertaining to both types of management, were compared in bar graphs.

2.2.10 Participatory evaluation

Participatory evaluations with each producer were carried out following methods outlined by Coe (2012) (Appendix 5). The characteristics evaluated were the farmer-preferred traits defined at the beginning of the study. Aside from the scores per farmer-preferred trait that farmers assigned, they also assigned an overall score to each tomato and sweet pepper variety. Farmer-preferred traits and farmer-varietal scores were used to determine whether farmers identify more interesting varieties for crop diversification when they have increased varietal choice as opposed to when they have access only to current commercial seed supply.

Correspondence analyses of farmers' scores per trait were used to determine which varieties were most preferred by farmers for each farmer-preferred trait.

Dot plots were used to understand which varieties were most preferred by farmers according to three different methods. It was assumed that the overall score assigned to each variety by farmers was biased because the farmers assumed the commercial variety was the best, without taking into consideration each preferred trait that they indicated at the beginning of the study. In order to test this assumption, a comparison was done of overall farmers' scores; farmers' scores per variety taking into consideration scores for each characteristic of interest; and farmers' score per variety taking into considerating each weighted characteristic of interest. A weight was assigned to each farmer-preferred trait based on the number of farmers who indicated each trait as important at the beginning of the study. The higher the precentage of farmers who mentioned the characteristic as important, the higher the weight assigned (Appendix 2).

Data from the participatory evaluations was used to explore how farmers' preferences differ according to altitudes (above 1,000 meters and below 1,000 meters) and under different types of management (conventional and organic). Extended and mixed linear models and correspondence analyses were carried out to explore these differences.

2.2.11 Morphological characterization

Minimum characterization and evaluation descriptors defined by IPGRI/CATIE (IPGRI 1995;IPGRI 1996), as well as additional descriptors that responded to farmer-preferred characteristics were taken into account. The additional descriptors for tomato include plant width, branching habit, fruit wall thickness and seed surface texture. The original minimum descriptor "weight of 1,000 seeds" was replaced by "weight of 100 seeds." The only minimum descriptors for tomato that were excluded were fruit size and pedicel scar width. Fruit weight, length and width already represent fruit size. Pedicel scar width was not of great importance in this study. Additional descriptors for sweet pepper included plant canopy width, leaf density and fruit wall thickness. Minimum descriptor for sweet pepper that were excluded included life cycle, male sterility and number of seeds per fruit because they were not relevant to purposes of the current study.

Extended and mixed linear models and correspondence analyses were used to determine which varieties perform better according to the farmer-preferred traits of interest.

Extended and mixed linear models and Nonparametric Kruskal-Wallis tests were used to determine significant interactions among the variables of interest.

The materials that perform best in different altitudes and under different types of management were defined using extended and mixed linear models and correspondence analyses.

Incidence of important pests and diseases for each crop was measured according to the IPGRI descriptors (IPGRI *et al.* 1995;IPGRI 1996). Tomato pests and diseases evaluated included *Phytophthora, Alternaria, Pseudomonas*, bacterial infection and *Aleyrodidae*. Sweet pepper pests and diseases evaluated included *Cercospora*, *Pseudomonas,* *Podosphaera*, bacterial infection, virus, *Aphidoidea.* Nutrient deficiency was also included in the analysis. These were evaluated because they are the most important pests and diseases in tomato and sweet pepper crops in the tropics. Furthermore, *Phytophthora* and *Alternaria* for tomato and *Cercospora* and *Pseudomonas* for sweet pepper were considered in more detail because they are the most important diseases of the two crops. Incidence was evaluated at four different intervals of the plant cycle: 1) between 45 and 90 days after planting, 2) between 91 and 120 days after planting, 3) between 121 and 150 days after planting and 4) between 151 and 180 days after planting.

In some cases, extended and mixed linear models and Nonparametric Kruskal-Wallis tests showed that there were no significant differences among varieties. In these cases, the most successful variety was determined by the highest mean for each farmer-preferred trait of interest.

2.2.12 Participatory evaluation versus morphological characterization

Results from the farmers' participatory evaluation and morphological characterization and evaluation were used to determine whether farmers prefer the same varieties that were shown as most successful by characterization for each farmer-preferred trait. The farmer-preferred traits were matched with characterization descriptors to make the comparison. There were additional farmer-preferred traits that were evaluated in this study that were not included in the IPGRI descriptors, including: for tomatoes—good flavor, sweet fruit, fruit lasts longer after harvest and fruit fit for market; for sweet peppers—fruit firmness.

Correspondence analyses were used to determine the variety most preferred by farmers according to each farmer-preferred trait. Extended and mixed linear models of the characterization data were used to determine the most successful varieties according to each quantitative farmer-preferred trait. Correspondence analyses using characterization data were used to determine the most successful varieties according to each qualitative farmer-preferred trait.

For the traits that did not show a significant difference among varieties, in terms of morphological characterization, the most successful variety was determined by the highest mean for each trait of interest.

2.2.13 Final interviews

Final, semi structured interviews regarding farmer opinions on the participatory evaluation process, genebank access and general opinions about the current project were carried out at the end of the study (Appendix 6).

2.3 Results

2.3.1 Farmer crop selection and farmer-preferred characteristics

Of the four crop options given to farmers, the majority of the producers expressed interest in planting tomato and sweet pepper, 11 and 8, respectively (Table 6).

Table 6. Number of farmers interested in planting each crop offered

New crop	Number of interested farmers
Tomato	11
Sweet pepper	8
Hot pepper	2
Squash	6

The most farmer-preferred traits for tomato, in order of priority, were high pest and disease resistance, medium to large fruit size, dark red fruit pulp, sweet fruit, high yield, juicy fruit, meaty fruit, firm fruit, fruit that lasts longer after harvest, tall plant size and a fruit that is well fit for the market. The most preferred traits for sweet pepper, in order of priority, were large fruit size, high pest and disease resistance, thick fruit skin, meaty fruit flesh, sweet fruit, high yield, firm fruit, fruit that lasts longer after harvest, long fruit, resistance to rain, square fruit form and yellow or red fruit color (Table 7).

Table 7. Priority and weights assigned to each farmer-preferred characteristic and morphological descriptor used in the study

Crop	Farmer-preferred characteristic	Scientific descriptor	Descriptor used in participatory evaluation	Number of farmers	Weight	Priority
Tomato	Pest and disease incidence low	Susceptibility to stress	Resistance to pests and diseases	6	0.21	+++++
Tomato	Medium-size fruit	Fruit weight	Fruit size	4	0.14	++++
Tomato	Dark red fruit	Color of pulp	Red fruit	4	0.14	++++
Tomato	Sweet fruit	N/A	Good flavor	3	0.1	+++
Tomato	Sweet fruit	N/A	Sweet fruit	3	0.1	+++
Tomato	High yield	Fruit yield	Yield	2	0.07	++
Tomato	Juicy fruit	Width of endocarp	Juicy fruit	2	0.07	++
Tomato	Meaty/ fleshy fruit	Width of pericarp	Meaty flesh	1	0.03	+
Tomato	Firm fruit	Firmness of fruit	Firm fruit	1	0.03	+
Tomato	Fruit that lasts longer after harvest	N/A	Fruit lasts longer after harvest	1	0.03	+

Tomato	Tall plant size	Height of plant	Preferable plant height	1	0.03	+
Tomato	Pre-established niche market	N/A	Fit for market	1	0.03	+
Pepper	Fruit size	Fruit weight	Fruit size	6	0.207	++++
Pepper	Fruit size	Fruit width	Fruit size	6	0.207	++++
Pepper	Pest and disease resistance	Pest and disease resistance	Pest and disease resistance	4	0.138	+++
Pepper	Thick skin	Width of fruit wall	Thick skin	2	0.069	++
Pepper	Meaty fruit flesh	Width of fruit wall	Meaty flesh	2	0.069	++
Pepper	Sweet fruit	N/A	Good flavor	1	0.034	+
Pepper	High yield	Fruit yield	Yield	1	0.034	+
Pepper	Firm fruit	N/A	Firm fruit	1	0.034	+
Pepper	Fruit that lasts longer after harvest	N/A	Fruit lasts longer after harvest	1	0.034	+
Pepper	Long fruit	Fruit length	Long fruit	1	0.034	+
Pepper	Resistance to rain	N/A	Resistance to rain	1	0.034	+
Pepper	Square shaped	Fruit shape	N/A	1	0.034	+
Pepper	Yellow colored	Fruit color	Preferable fruit color	1	0.034	+
Pepper	Red colored	Fruit color	Preferable fruit color	1	0.034	+

2.3.2 Climate information

The farms above 1,000 meters had an average temperature of 21.4°C, maximum temperature of 33.5°C, minimum temperature of 14.4°C, average humidity of 95.4%, maximum humidity of 104% and minimum humidity of 43.7%. The farms below 1,000 meters had an average temperature of 22.3°C, maximum temperature of 34.4°C, minimum temperature of 15.8°C, average humidity of 96%, maximum humidity of 104.4% and minimum humidity of 45.7% (Table 8).

Table 8. Climate information collected from iButtons for each farm in the current study

Producer	Avg temp (°C)	Max temp (°C)	Min temp (°C)	Avg humidity (%)	Max humidity (%)	Min humidity (%)
Daniel	21.5	33.5	13.7	95.1	103.4	45.1
Jorge	21.0	33.3	15.2	96.0	103.1	43.4
Enrique	21.4	32.8	14.6	95.4	104.1	43.2

Carlos	21.6	34.4	14.1	95.2	105.6	42.8
Avg high altitude	21.4	33.5	14.4	95.4	104.0	43.7
Benedicto	22.0	33.3	16.4	99.9	106.7	50.2
Celso	21.4	34.1	15.5	96.2	103.8	47.3
Rosa	23.0	36.0	15.8	94.3	103.4	41.3
Edgar	22.8	34.0	15.4	93.7	103.7	43.9
Avg low altitude	22.3	34.4	15.8	96.0	104.4	45.7

2.3.3 Farmers' experience with vegetable crop management

Farmers excelled in weed management, providing plant support (tying up tomato and sweet pepper plants to support the branches and fruit), farmer-led management and timely application of provided inputs. Management by farmers was lacking with respect to water drainage, plant trimming and pruning, removal of infected plant parts from the plant and the plot, and proper preparation of row height for the rows where the plants were planted (Fig. 3). In general, organic farmers had more refined management practices than the conventional farmers (Fig. 4).

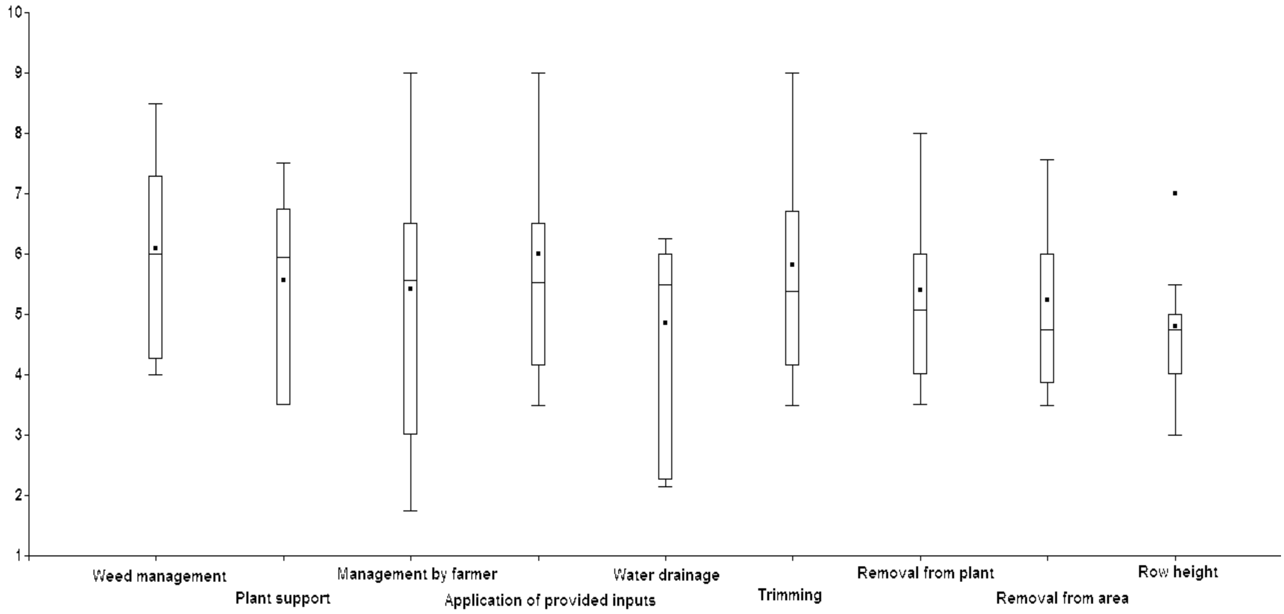

Figure 3. Bar graph of average farmer-management scores.

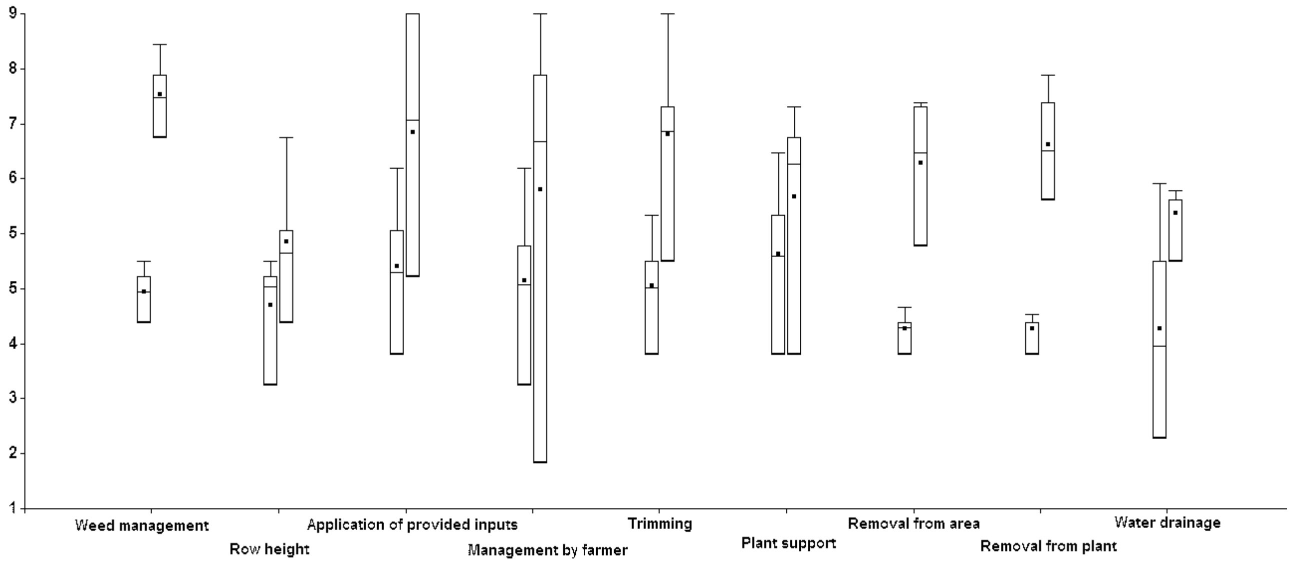

Figure 4. Bar graph of average farmer-management scores under both types of management

Note: left = conventional, right = organic

2.3.4 Farmers' preferences with increased varietal supply

Extended and mixed linear models showed that the farmers' overall preferences varied among the tomato and sweet pepper varieties. A significant difference in the farmers' overall score per variety was found for both crops: tomato f = 1.94, p = 0.05; sweet pepper f = 4.51, p =0.0001 (extended and mixed linear models). Significant difference in the farmers' score for each variety taking into consideration scores per trait was also found: tomato f = 2.88, p = 0.004; sweet pepper f = 7.64, p = 0.0001 (extended and mixed linear models). Comparing the farmers' score for each variety taking into consideration weighted scores per trait also illustrated differences among varieties: tomato f = 3.03, p = 0.003; sweet pepper f = 8.59, p = 0.0001, (extended and mixed linear models).

Figure 5 shows that among tomato varieties, the Commercial1 variety was scored highest by farmers for fruit size as well as good fit for the market. However apart from these two farmer-preferred traits, CATIE accessions and AVRDC varieties were scored higher for other preferred traits. CATIE random2 was scored highest for pest and disease resistance, while CATIE select1, CATIE select3, CATIE select4 and CATIE random3 all scored very high for red fruit pulp, good flavor, sweet fruit and fruit juiciness according to farmers. CATIE select 5 was scored highest for yield. CATIE select2 and AVRDC1 were scored highest for fruit firmness and meaty flesh. According to farmers, CATIE random1 had the most preferable plant height.

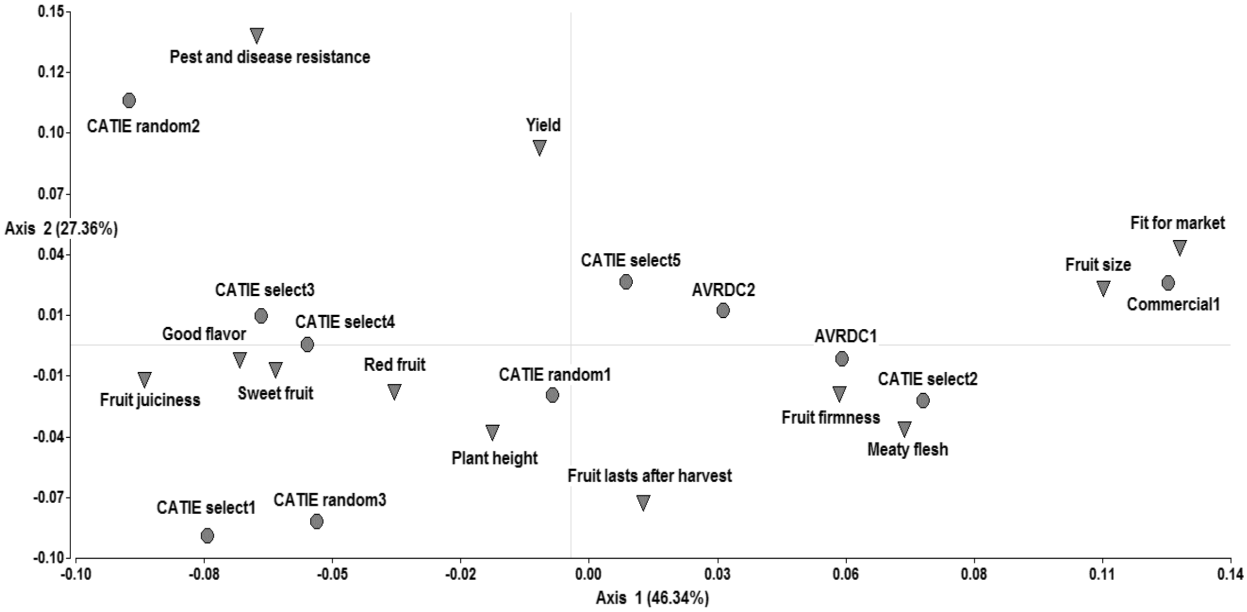

Figure 5. Correspondence analysis of tomato varieties and accessions and farmers' scores by farmer-preferred traits
Note: triangle = fruit characteristic, circle = variety or accession

Figure 6 shows that for sweet pepper varieties, while Commercial1, Commercial2 and AVRDC2 were most directly related to larger fruit size, CATIE accessions and AVRDC varieties were scored higher in other preferred traits. CATIE select1, CATIE random2 and CATIE random3 were scored high for traits such as fruit lasts longer after harvest, good flavor, fruit firmness and desirable fruit color. CATIE select2 and AVRDC2 were scored best for fruit skin thickness and meaty flesh. CATIE select3 and AVRDC3 were scored highest for pest and disease resistance and resistance to rain. Commercial2 and AVRDC3 were scored highest for yield.

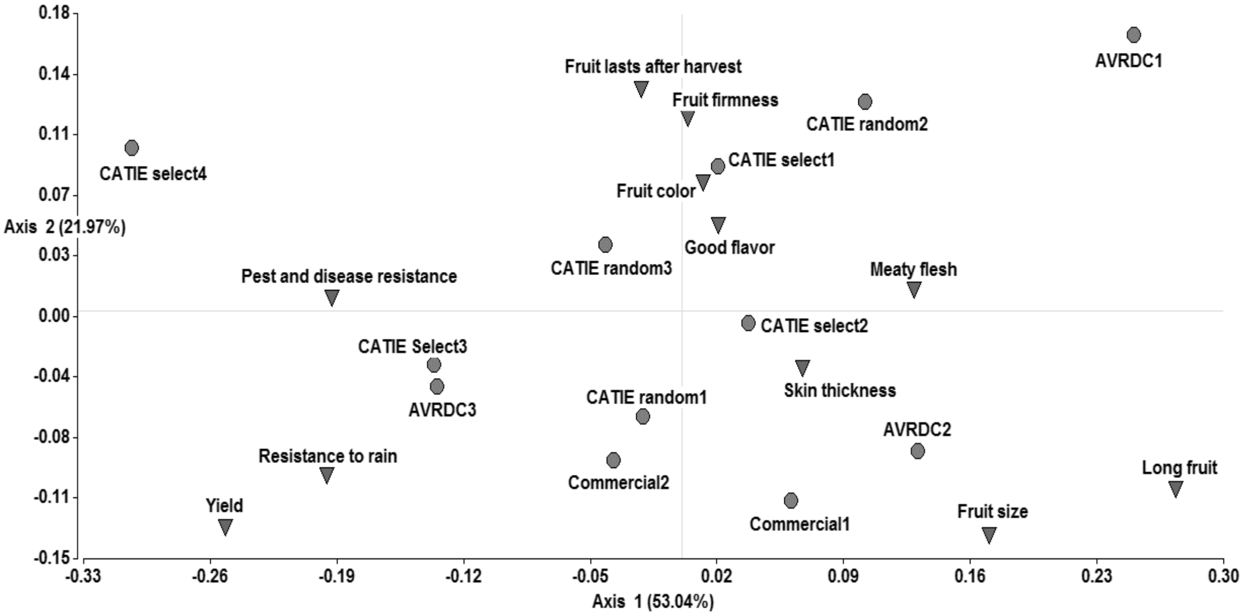

Figure 6. Correspondence analysis of sweet pepper varieties and accessions and farmers' scores by farmer-preferred traits

Note: triangle = fruit characteristic, circle = variety or accession

Figure 7 and Figure 8 show that the varieties were scored differently when the three different scoring methods mentioned above (average overall variety score, score per variety taking into consideration farmers' preferred traits and score per variety taking into consideration weighted farmer-preferred traits) were applied to tomato and sweet pepper varieties. The dot plot in figure 7 shows that farmers' peferences changed when comparing average overall score and average score of all farmer-preferred traits for tomato varieties. For example, among tomato varieties, Commercial1 was scored as more preferred according to the overall score and score per variety taking into consideration farmer-preferred traits, however CATIE random2 was the most preferred according to score per variety taking into consideration weighted farmer-preferred traits. This shows the assumption may be true that the average overall varietal scores are not very representative of actual farmers' preferences because the farmers did not take into consideration accurately all preferred traits at the time of assigning an overall score.

When using the farmers' average overall varietal score and score per variety taking into consideration farmer-preferred traits to compare tomato varieties, farmers preferred the Commercial1 variety. However, when the score per variety taking into consideration weighted farmer-preferred traits was used, CATIE random2 was shown to be the most preferred (Fig 7).

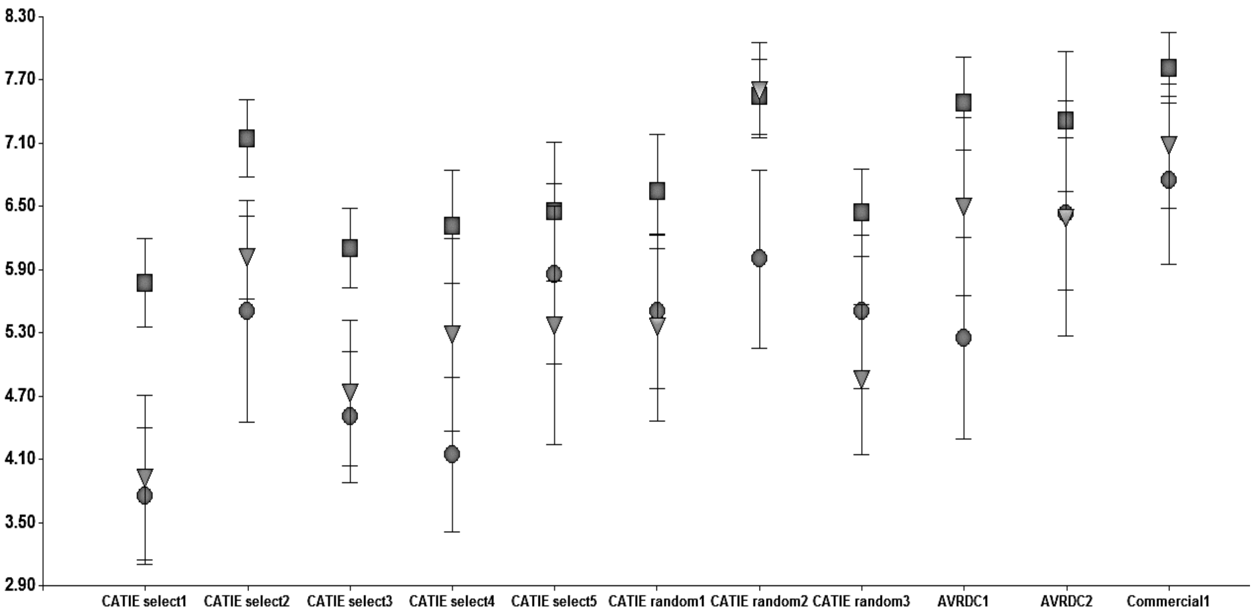

Figure 7. Dot plot of farmers' preferences for tomato varieties and accessions

Note: circle = farmers' average overall score, square = score per variety taking into consideration farmer-preferred traits, triangle = score per variety taking into consideration weighted farmer-preferred traits

Figure 8 shows that preferences changed when comparing farmers' average overall varietal score and score per variety taking into consideration farmer-preferred traits for sweet pepper varieties. For example, Commercial2 was scored as more preferred than AVRDC1 when comparing farmers' average overall varietal score. However, when the farmers' score per variety taking into consideration farmer-preferred traits was compared, AVRDC1 was more preferred than Commercial2.

For sweet pepper varieties, Commercia1 was the most preferred using all three methods of scoring. This shows that even with the weights assigned to each preferred trait, Commercial1 was still the most preferred variety. The second most preferred sweet pepper variety when comparing the farmer's overall varietal score was accession CATIE select3. However, when comparing the score per variety taking into consideration weighted farmer-preferred traits, AVRDC2 was the second most preferred variety (Fig. 8).

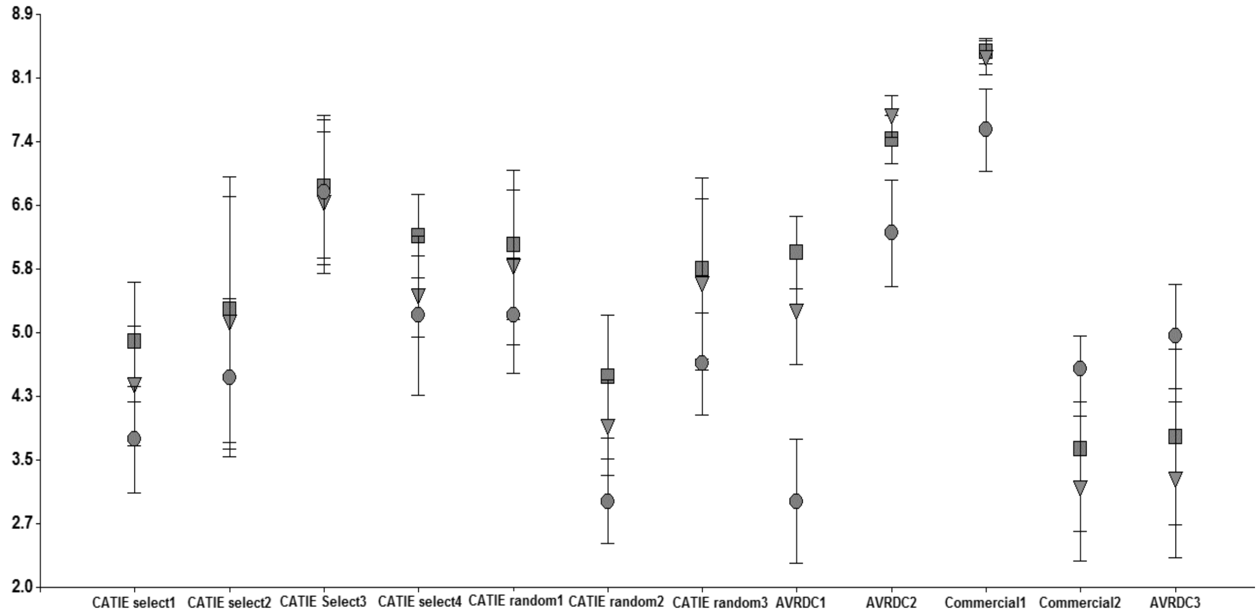

Figure 8. Dot plot of farmers' preferences for sweet pepper varieties and accessions

Note: circle = average farmers' overall score, square = farmers' score per variety taking into consideration farmer-preferred traits, triangle = farmers' score per variety taking into consideration weighted farmer-preferred traits

2.3.5 Farmers' preferences in different altitudes and under different types of management

Farmers' preferences regarding tomato varieties remained similar across altitudes and between management types, and no significant interactions were found among variety, altitude and management (Table 9). Among sweet pepper varieties, farmers' preferences changed according to different altitudes and under different types of management; however, the triple interaction for sweet pepper varieties was not significant (Table 9).

Table 9. Identification of interactions between variety, altitude and type of management considering farmers' overall scores for sweet pepper varieties and accessions

Crop	Altitude* management* variety	Altitude* variety	Management* variety
Pepper	49.68	36.48*	38.21**
Tomato	36.31	17.4	24.25

Note: * Significant at $p \leq 0.05$, ** $p \leq 0.01$; *** $p \leq 0.001$
Note: Nonparametric Kruskal-Wallis; H values

It is clear that farmers' preferences for sweet pepper varieties changed significantly at different altitudes and under different types of management.

Farmers at low altitudes and using organic management preferred the AVRDC (AVRDC3) and commercial (Commercial2) sweet pepper varieties, while farmers at low altitudes using conventional management preferred CATIE accessions, both random (CATIE random2) and selected (CATIE select2). Farmers at high altitudes using organic management preferred CATIE select (CATIE select1, CATIE select3, CATIE select4) and

CATIE random (CATIE random1) varieties and farmers at high altitudes using conventional management scored CATIE random (CATIE random3) accessions and AVRDC (AVRDC1) varieties highest. These differences may be due to diverse farmer-preferred traits at different altitudes or under different types of management. They also may be due to better performance, measured by scientific descriptors, of certain accessions or varieties at different altitudes or under different types of management (Fig. 9).

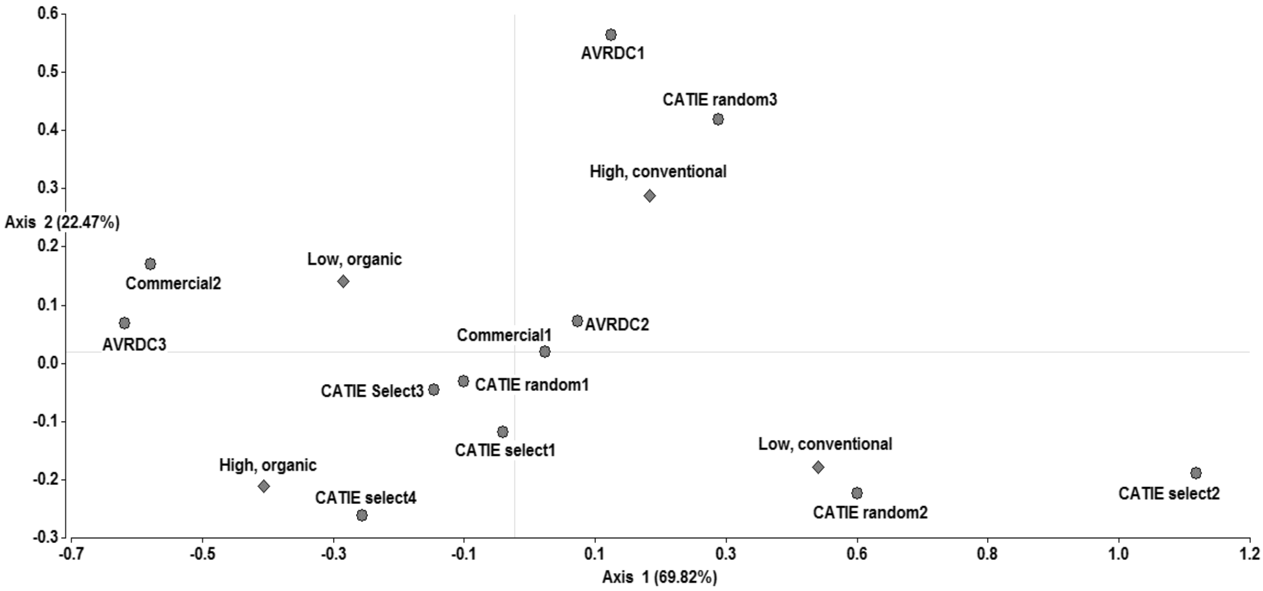

Figure 9. Correspondence analysis demonstrating farmer-preferred sweet pepper varieties and accessions at both altitudes and under both types of management
Note: diamond = altitude, type of management; circle = variety or accession

2.3.6 Morphological characterization and the effects of altitude and type of management on varietal performance

2.3.6.1 Variety comparison

According to extended and mixed linear models and correspondence analyses, the commercial tomato variety had the highest fruit weight. However, apart from fruit weight, CATIE accessions and improved AVRDC varieties dominated other preferred traits. AVRDC2 had the highest resistance to pest and disease in general, as well as to *Phytopthora* and *Alternaria*. For the other traits of interest, CATIE select accessions, CATIE random accessions and AVRDC varieties all showed the best results (Table 10).

For sweet pepper varieties, the commercial and improved AVRDC varieties dominated fruit size (fruit weight, fruit width and fruit length) as well as width of fruit wall and resistance to *Pseudomonas*. CATIE select3 had the highest resistance to pests and diseases in general and CATIE select 4 had the highest resistance to *Cercospora* (Table 10).

Table 10. Identification of most successful tomato and sweet pepper varieties according to morphological characterization and evaluation data for each farmer-preferred trait

Crop	Descriptor	Best variety or accession
Tomato	Pest and disease resistance	AVRDC2
Tomato	*Phytophthora*	AVRDC2
Tomato	*Alternaria*	AVRDC2
Tomato	Fruit weight	Commercial1
Tomato	Color of pulp	CATIE select2
Tomato	Endocarp width	CATIE random1
Tomato	Pericarp width	AVRDC1
Tomato	Fruit firmness	AVRDC2, CATIE select1
Tomato	Plant height	AVRDC1
Pepper	Fruit weight	AVRDC2
Pepper	Fruit width	AVRDC2
Pepper	Pest and disease resistance	CATIE select3
Pepper	*Cercospora*	CATIE select4
Pepper	*Pseudomonas*	Commercial1
Pepper	Width of fruit wall	AVRDC2
Pepper	Fruit length	Commercial2
Pepper	Fruit form	Commercial1, AVRDC2
Pepper	Fruit color	CATIE random1, AVRDC2

Note: Extended and mixed linear models and correspondence analyses

For most of the quantitative and qualitative morphological characterization descriptors of interest, significant differences between tomato and sweet pepper varieties were found. The effects of altitude and management on tomato and sweet pepper on their own were not significant; however, the interactions between altitude and variety and between management and variety were very significant for both crops (Table 11).

Looking more closely at specific pest and disease resistances among tomato and sweet pepper varieties, characterization data illustrated that there were significant interactions between tomato variety, altitude and management, variety and management and variety and altitude when comparing resistance in general and, more specifically, to *Phytophthora* and *Alternaria.* Sweet pepper varieties, however, only revealed a significant interaction between management and variety when comparing resistances of the varieties to *Cercospora*. There were no significant interactions found when comparing the resistance of sweet pepper varieties to pest and disease in general nor to *Pseudomonas* (Table 11).

For tomato varieties, AVRDC2 had the highest resistance to all pests and disease under organic management and at low altitudes. Under conventional management, CATIE random2 had the highest resistance to pests and diseases in general as well as to *Phytophthora,* while CATIE select5 had the highest resistance to *Alternaria*. At high altitudes, CATIE select 5 had the highest resistance to pests and disease in general and to *Phytophthora,* while AVRDC2 demonstrated the highest resistance to *Alternaria* (Table 12).

For sweet pepper varieties under organic management, CATIE select3 had the highest resistance to pests and disease in general as well as to *Pseudomonas*, while CATIE select1 had the highest resistance to *Cercospora*. Under conventional management, Commercial1 variety showed the highest resistance to pests and disease in general, while CATIE select4 had the highest resistance to *Cercospora*. At low altitudes, CATIE select3 revealed the highest resistance to pests and disease in general, CATIE random2 to *Cercospora* and AVRDC3 to *Pseudomonas*. At high altitudes, CATIE select3 had the highest resistance to both pests and disease in general as well as to *Cercospora*, while CATIE random3 had the highest resistance to *Pseudomonas* (Table 12).

Table 11. Identification of interactions among variety, altitude and type of management considering tomato and sweet pepper characterization and evaluation data

Crop	Attribute	Altitude (A)	Management (M)	Variety (V)	A*V	M*V	A*M*V
Tomato	Pest and disease resistance	1.96	0.09	10.05***	4.91***	4.92***	2.68***
Tomato	*Phytophthora*	2.4	0.04	3.78***	2.42**	2.74***	2.02**
Tomato	*Alternaria*	0.02	0.09	19.2***	8.66***	10.33***	4.95***
Tomato	Fruit weight	0.34	2.23	12.19***	5.10***	6.12***	2.97**
Tomato	Color of pulp	0.04	0.39	12.59	22.49	12.84	33.81
Tomato	Endocarp width	0.01	1.15	14.93***	7.8***	7.23***	5.18***
Tomato	Pericarp width	0.04	7.96*	4.5***	2.24**	2.82**	1.67
Tomato	Fruit firmness	0.07	0.01	8.9	12.35	-0.67	21.65
Tomato	Plant height	0.08	0.18	5.22***	3.34***	2.97**	2.5**
Pepper	Fruit weight	0.35	0.16	9.69***	3.98***	5.36***	2.55**
Pepper	Fruit width	0.26	0.03	19.49***	10.85***	8.61***	5.3***
Pepper	Pest and disease resistance	0.61	0.16	1.14	1.06	1	1.03
Pepper	*Cercospora*	0.9	2.05	2.83**	1.62	2.63**	1.71
Pepper	*Pseudomonas*	1.38	3.41	1.75	1.21	1.3	1.5

Pepper	Width of fruit wall	0.23	0.08	10.2***	5.94***	5.34***	2.49*
Pepper	Fruit length	0.39	0.73	14.0***	7.14***	7.56***	3.6**
Pepper	Fruit form	0.01	1.10E-03	44.2***	46.58***	45.82***	51.33*
Pepper	Color of mature fruit	0.04	0.07	37.82***	46.33***	44.30***	53.44*

Note: * Significant at $p \leq 0.05$, ** $p \leq 0.01$; *** $p \leq 0.001$
Note: Extended and mixed linear models to compare quantitative descriptors; values per trait and interaction are expressed as F values. Nonparametric Kruskall-Wallis to compare qualitative descriptors; values per trait and interaction expressed as H values.
Note: Pest and disease resistance for tomato includes resistance to *Phytophthora, Alternaria*, *Pseudomonas*, fruit bacteria and *Aleyrodidae.*
Note: Pest and disease resistance for sweet pepper includes resistance to *Cercospora, Pseudomonas*, fruit bacteria, Virus, *Aphidoidea* and nutrient deficiency.

Table 12. Best tomato and sweet pepper varieties for each preferred trait under both types of management and at each altitude according to morphological characterization and evaluation

Crop	Trait	Organic	Conventional	Low	High
Tomato	Pest and disease resistance	AVRDC2	CATIE random2	AVRDC2	CATIE select5
Tomato	*Phytophthora*	AVRDC2	CATIE random2	AVRDC2	CATIE select5
Tomato	*Alternaria*	AVRDC2	CATIE select5	AVRDC2	AVRDC2
Tomato	Fruit weight	Commercial1	CATIE select2	CATIE Select2	Commercial1
Tomato	Color of pulp	AVRDC1, AVRDC2	AVRDC1, AVRDC2	AVRDC1, AVRDC2	AVRDC1, AVRDC2
Tomato	Endocarp width	CATIE select2	CATIE random1	CATIE select5	Commercial1
Tomato	Pericarp width	AVRDC1	AVRDC1	AVRDC1	AVRDC1
Tomato	Fruit firmness	CATIE select1, CATIE select4, AVRDC2	CATIE select1, CATIE select4, AVRDC2	CATIE select1, CATIE select4, AVRDC2	CATIE select1, CATIE select4, AVRDC2
Tomato	Plant height	AVRDC1	AVRDC1	CATIE random2	AVRDC1
Pepper	Fruit weight	Commercial2	AVRDC1	Commercial2	AVRDC2
Pepper	Fruit width	AVRDC2	AVRDC2	AVRDC2	AVRDC2
Pepper	Pest and disease resistance	CATIE select3	Commercial1	CATIE Select3	CATIE select3
Pepper	*Cercospora*	CATIE select1	CATIE select4	CATIE random2	CATIE select3
Pepper	*Pseudomonas*	CATIE select3	Commercial1	AVRDC3	CATIE

					random3
Pepper	Width of fruit wall	AVRDC3	AVRDC2	AVRDC3	AVRDC2
Pepper	Fruit length	AVRDC3	Commercial2	CATIE select2	Commercial2
Pepper	Fruit form	Commercial1, AVRDC1, AVRDC3	Commercial1, AVRDC1, AVRDC3	Commercial1, AVRDC1, AVRDC3	Commercial1, AVRDC1, AVRDC3
Pepper	Fruit color	CATIE random1, CATIE, random2 CATIE Select1, AVRDC1, AVRDC2	CATIE random1, CATIE, random2 CATIE select1, AVRDC1, AVRDC2	CATIE random1, CATIE, random2 CATIE select1, AVRDC1, AVRDC2	CATIE random1, CATIE, random2 CATIE select1, AVRDC1, AVRDC2

Note: Extended and linear mixed models and nonparametric Kruskal-Wallis.

2.3.6.2 Group comparisons

Extended and mixed linear models and correspondence analyses showed that different groups of tomato and sweet pepper varieties were most successful according to specific farmer-preferred traits (Table 13).

When comparing morphological data per trait across tomato variety groups, the commercial variety group demonstrated the largest fruit-size results (fruit weight, endocarp width, pericarp width) as well as best plant height. The CATIE random accession group showed the highest resistance to pests and diseases in general as well as more specifically to *Phytophthora* and *Alternaria.* The AVRDC groups appeared to have the best pulp color, while the CATIE select group had the best fruit firmness (Table 13).

Morphological data for sweet pepper groups showed that the commercial variety group and improved AVRDC variety group were the most successful in fruit size (fruit weight, fruit width and fruit length). The commercial group had the highest resistance to *Pseudomonas;* however, the CATIE select group had the highest resistance to pests and diseases in general as well as to *Cercospora*. The commercial variety group had the most preferable fruit form. The AVRDC group was most successful in width of the fruit wall and fruit color (Table 13).

Table 13. Most successful tomato and sweet pepper variety groups according to morphological characterization and evaluation data for each farmer-preferred trait

Crop	Descriptor	Best variety group or accession group
Tomato	Pest and disease resistance	CATIE random
Tomato	*Phytophthora*	CATIE random
Tomato	*Alternaria*	CATIE random
Tomato	Fruit weight	Commercial
Tomato	Color of pulp	AVRDC

Tomato	Endocarp width	Commercial
Tomato	Pericarp width	Commercial
Tomato	Fruit firmness	CATIE select
Tomato	Plant height	Commercial
Pepper	Fruit weight	Commercial
Pepper	Fruit width	AVRDC
Pepper	Pest and disease resistance	CATIE select
Pepper	*Cercospora*	CATIE select
Pepper	*Pseudomonas*	Commercial
Pepper	Width of fruit wall	AVRDC
Pepper	Fruit length	Commercial
Pepper	Fruit form	Commercial
Pepper	Fruit color	AVRDC, Commercial

Note: Extended and mixed linear models and correspondence analyses

There were significant interactions between altitude and group; management and group and altitude; management and group among sweet pepper groups; and a few significant interactions among tomato variety groups (Table 14).

For tomato varieties under organic management, commercial and CATIE random groups were most frequently regarded as the best. Under conventional, management, commercial, CATIE select and CATIE random most frequently appeared to be the best. At low altitudes, commercial and CATIE random groups were most frequently displayed as best according to preferred characteristics. At high altitudes, commercial and CATIE select groups were most frequently displayed as best according to preferred characteristics (Table 15).

For sweet pepper varieties, commercial and AVRDC groups were most frequently the best under both types of management and both altitudes (Table 15).

Looking at pest and disease resistance more closely, it is noted that tomato resistance to pests and diseases in general and to *Alternaria* was significantly different among groups. There was also a significant interaction between management and variety group when comparing resistance to *Alternaria*. No significant interactions appeared when comparing resistance to *Phytophthora* among tomato groups. For sweet pepper, no significant interactions among groups appeared when looking at resistance to pests and diseases in general. However, when comparing resistance to *Cercospora*, there was a significant interaction between altitude and group, management and group as well as the triple interaction between altitude, management and group. Resistance to *Pseudomonas* revealed a significant interaction only when looking at the triple interaction between altitude, management and group (Table 14).

The CATIE random group for tomato had the highest resistance to pests and diseases in general at both altitudes and under both types of management as well as to *Phytophthora* at low altitudes and under conventional management. The CATIE select group showed the highest resistance, more specifically to *Phytophthora* at high altitudes under organic management and to *Alternaria* at high altitudes and under conventional management. The

CATIE random group was the most resistant to *Alternaria* at low altitudes and under organic management, while the CATIE select group was most resistant to *Alternaria* under conventional management at high altitudes (Table 15).

For sweet pepper varieties, CATIE select accessions had the highest resistance to pests and disease in general at high altitudes and under organic management. The CATIE random group showed the highest resistance in general at low altitudes, and the commercial variety group showed the highest resistance under conventional management. The CATIE select accession group showed highest resistance to *Cercospora* at high altitudes and under organic management, while CATIE random group demonstrated the highest resistance at low altitudes and under conventional management. The AVRDC variety group had the highest resistance to *Pseudomonas* at low altitudes and under organic management, while the commercial variety group had more resistance at high altitudes and under conventional management (Table 15).

Table 14. Identification of interactions among group, altitude and type of management considering tomato and sweet pepper characterization data

Crop	Trait	Altitude (A)	Management (M)	Group (G)	A*G	M*G	A*M*G
Tom.	Pest and disease resistance	1.96	0.09	3.55**	1.82	1.54	1.17
Tom.	*Phytophthora*	2.4	0.04	1.83	1.17	1.02	0.77
Tom.	*Alternaria*	0.02	0.09	4.87**	2.02	2.07*	1.7
Tom.	Fruit weight	0.1	1.46	3.34*	1.14*	1.7	1.61
Tom.	Color of pulp	0.04	0.39	1.99	3.85	6.2	8.95
Tom.	Endocarp width	0.01	1.15	3.38*	1.84	1.75	1.59
Tom.	Pericarp width	0.04	7.96*	3.73**	1.57	3.19**	1.64
Tom.	Fruit firmness	0.07	0.01	2.43	2.75	5.15	7.32
Tom.	Plant height	0.02	0.13	1.3	1.13	1.01	0.92
Pepp.	Fruit weight	0.36	0.16	32.65***	16.35***	13.79***	7.39***
Pepp.	Fruit width	0.26	0.03	27.67***	12.75***	11.62***	5.9***
Pepp.	Pest and disease resistance	0.61	0.16	0.35	0.57	0.63	0.67
Pepp.	*Cercospora*	0.9	2.05	5.2**	2.39*	3.75***	2.26**
Pepp.	*Pseudomonas*	1.38	3.41	2.34	1.42	1.81	2.04*
Pepp.	Width of fruit wall	0.23	0.08	31.44***	13.07***	13.05***	5.69***
Pepp.	Fruit length	0.39	0.73	23.44***	9.61***	10.14***	4.53***
Pepp.	Fruit form	0.01	1.10E-03	23.5***	23.99***	23.98***	25.67*
Pepp.	Color of mature fruit	0.04	0.07	9.83**	11.77	11.48	14.19

Note: * Significant at $p \leq 0.05$, ** $p \leq 0.01$; *** $p \leq 0.001$

Note: Extended and mixed linear models to compare quantitative descriptors; values per trait and interaction expressed as F values. Nonparametric Kruskall-Wallis used to compare qualitative descriptors; values per trait and interaction expressed as H values.

Table 15. Most successful tomato and sweet pepper groups under both types of management and at each altitude according to morphological characterization and evaluation

Crop	Trait	Organic	Conventional	Low	High
Tomato	Pest and disease resistance	CATIE random	CATIE random	CATIE random	CATIE random
Tomato	*Phytophthora*	CATIE select	CATIE random	CATIE random	CATIE select
Tomato	*Alternaria*	CATIE random	CATIE select	CATIE random	CATIE select
Tomato	fruit weight	Commercial	Commercial	Commercial	Commercial
Tomato	Color of pulp	Commercial	CATIE select	CATIE select, Commercial	Commercial, CATIE random
Tomato	Endocarp width	Commercial	Commercial	Commercial	Commercial
Tomato	Pericarp width	Commercial	AVRDC	Commercial	AVRDC
Tomato	Fruit firmness	AVRDC	CATIE select	AVRDC	CATIE select
Tomato	Plant height	Commercial	Commercial	Commercial	Commercial
Pepper	Fruit weight	AVRDC	Commercial	Commercial	AVRDC
Pepper	Fruit width	AVRDC	AVRDC	AVRDC	AVRDC
Pepper	Pest and disease resistance	CATIE select	Commercial	CATIE random	CATIE select
Pepper	*Cercospora*	CATIE select	CATIE random	CATIE random	CATIE select
Pepper	*Pseudomonas*	AVRDC	Commercial	AVRDC	Commercial
Pepper	Width of fruit wall	AVRDC	AVRDC	Commercial	AVRDC
Pepper	Fruit length	Commercial	Commercial	Commercial	Commercial
Pepper	Fruit form	AVRDC, Commercial	AVRDC, Commercial	AVRDC, Commercial	AVRDC, Commercial
Pepper	Fruit color	AVRDC, Commercial	AVRDC, Commercial	AVRDC, Commercial	AVRDC, Commercial

Note: Extended and mixed linear models and nonparametric Kruskal-Wallis.

2.3.7 Comparison of farmers' scores and characterization

There were notable differences between the varieties that the farmers scored as most successful per trait and the varieties that were most successful per descriptor according to characterization and evaluation data. Farmer-preferred traits could be easily paired with scientific descriptors: farmers were often searching for characteristics similar to those usually assessed in a scientific characterization.

Improved varieties, commercial and AVRDC of both tomato and sweet pepper crops tended to dominate the fruit weight descriptor category for tomato and sweet pepper as observed by farmers as well as in the morphological characterization. However, apart from fruit weight, CATIE accessions and AVRDC varieties of both tomato and sweet pepper tended to be the most favorable with respect to each trait according to farmers' preferences and scientific characterization. Farmers' preferences were dominated by CATIE select and CATIE random accessions, while scientific characterization identified CATIE select accessions and improved AVRDC varieties as most frequently successful (Table 16).

Table 16. Comparison of most successful varieties and accessions of tomato and sweet pepper according to farmers' preferences and scientific characterization and evaluation

Crop	Farmer-preferred characteristic	Scientific descriptor	Descriptor used in participatory evaluation	Farmer preferences	Scientific characterization
Tomato	Pest and disease incidence low	Susceptibili ty to stress	Resistance to pests and diseases	CATIE random2	AVRDC2
Tomato	Medium size fruit	Fruit weight	Fruit size	Commercial1	Commercial1
Tomato	Dark red fruit	Color of pulp	Red fruit	CATIE select4	CATIE select2
Tomato	Sweet fruit	N/A	Good flavor	CATIE select3	N/A
Tomato	Sweet fruit	N/A	Sweet fruit	CATIE select4	N/A
Tomato	Juicy fruit	Width of endocarp	Juicy fruit	CATIE select3, CATIE select1	CATIE random1
Tomato	Meaty/fleshy fruit	Width of pericarp	Meaty flesh	CATIE select2	AVRDC1
Tomato	Firm fruit	Firmness of fruit	Firm fruit	AVRDC1	AVRDC2, CATIE select1
Tomato	Fruit that lasts longer after harvest	N/A	Fruit that lasts longer after harvest	CATIE random1	N/A
Tomato	Tall plant size	Height of plant	Preferable plant height	CATIE random1	AVRDC1
Tomato	Fit for market	N/A	Fit for market	Commercial1	N/A
Pepper	Fruit size	fruit weight	Fruit size	AVRDC2	AVRDC2
Pepper	Fruit size	Fruit width	fruit size	AVRDC2	AVRDC2
Pepper	Pest and disease resistance	Pest and disease resistance	Resistance to pest and disease	CATIE select3	CATIE select3
Pepper	Skin thickness	Width of fruit wall	Thick skin	CATIE select2	AVRDC2
Pepper	Meaty flesh	Width of fruit wall	Meaty flesh	CATIE select2, AVRDC2	AVRDC2
Pepper	Fruit firmness	N/A	Firm fruit	CATIE select1	N/A

Pepper	Fruit lasts after harvest	N/A	Fruit that lasts longer after harvest	CATIE select1	N/A
Pepper	Resistance to rain	N/A	Resistance to rain	AVRDC3	N/A
Pepper	Fruit length	Fruit length	Long fruit	AVRDC2	Commercial2
Pepper	Square shaped	Fruit form	N/A	N/A	Commercial1, AVRDC2
Pepper	Yellow colored	Fruit color	Preferable fruit color	CATIE select1	CATIE random1, AVRDC2
Pepper	Red colored	Fruit color	Preferable fruit color	CATIE select1	CATIE random1, AVRDC2

Note: Extended and mixed linear models and correspondence analyses

2.3.8 Farmers' engagement and perspective on PVS for diversification

2.3.8.1 Participatory evaluation

All eight farmers said that during the study they discovered new varieties that demonstrated high resistance and were of high quality. The conventional farmers tended to seek varieties of both tomato and sweet pepper that had larger fruit size and higher yield, whereas the organic farmers tended to be more open to diversifying with varieties that produced smaller fruit and may not have had as high of a yield but had other important traits.

All of the farmers commented that the new varieties motivated them to either start or continue diversifying their farms with new crops as well as new varieties. They explained that because of drastically changing climate conditions, every year it is harder to find varieties adapted to their farms with sufficient resistance to pests and diseases. Many farmers had lost motivation for planting new crops because the currently available varieties are not adapted to new conditions, and oftentimes they revert back to focusing on the coffee plants.

2.3.8.2 Seeds

All eight farmers indicated that they do not like being dependent on seed companies or commercial nurseries to buy seeds or plants; they prefer to have their own seeds from open-pollinated varieties and accessions. Seven of the eight farmers, three organic and four conventional, had begun saving seeds from this project. The AVRDC varieties and CATIE accessions are not hybrids, therefore the farmers can continue to reproduce their own high-quality seeds and be less dependent on outside sources. However, none of the farmers in the study had either adequate resources or knowledge for appropriate seed saving.

The majority of the farmers also expressed dissatisfaction with the currently available commercial varieties, saying that they would like to have a broader range of varieties to choose from. All farmers claimed that they would benefit from enhanced access to genebanks, such as the one at CATIE; however, they all feel that the process to access the material in the genebank needs to be made easier and more understandable for all users.

One organic farmer at the higher altitude mentioned that he would like to see CATIE offer trays of seedlings of the traditional varieties in the genebank as an alternative to the commercially available trays found in local greenhouses.

2.3.8.3 Perceptions about the project

Every farmer, both organic and conventional, involved in the project said that the study was a valuable learning experience. All were interested in learning about and trying new open pollinated varieties and accessions to find crops and varieties that do best on their farms; however, all of them mentioned that they lack the support and proper access to varietal material to be able to do so on their own. Six farmers indicated that they like working in group projects such as this participatory evaluation because they learn more than when working alone.

All eight farmers mentioned that other projects, either supported by the government or private entities, often fail because there is not continued support and accompaniment throughout the project. Six of the farmers said that one thing they liked most about this participatory evaluation was that we visited the farms very often and they felt that they had a lot of technical and moral support.

All eight farmers in the study suggested that the project should have been planned more in advance and with better preparation, together with the farmer. The tomato and sweet pepper plants were planted during the rainiest part of the year due to project time constraints. This greatly affected the results of the study because many of the young plants experienced extreme climate conditions. All farmers also commented that they would have liked to have had more time to prepare the land before planting. Due to miscommunication, one organic farmer at the higher altitude removed some of the tomato plants before the study was finished. This farmer said that the confusion was due to miscommunication about how long the project would last and suggested that better explanations be given to the farmer at the beginning of the study.

One organic farmer at the higher altitude suggested that the project should have first planted the varieties and accessions that were selected for the project in a trial plot to make sure that each variety had market potential and preferable characteristics.

2.4 Discussion

Tomato and sweet pepper crops were most preferred by farmers for diversification according to the results of initial farmer interviews. Tomato is a high value, major commercial crop and has the potential to diversify farms and be a significant source of income for small-scale farmers (De La Peña and Hughes 2007;Oluoch *et al.* 2009;Gautam *et al.* 2013). Sweet pepper is another crop that has great potential for diversification because of the diversity that exists within the crop, most of which is still unexplored (Zonneveld *et al.* 2014). Vegetable crops in general have high commercial value and nutritional benefits that make them important for the diversification of any small-scale farming system (Ebert 2014).

Although all eight farmers initially expressed sincere interest in diversification with tomato and sweet pepper, not all of the farmers showed the same commitment throughout the project. The commitment to farmer-led management and various cultural practices of each farmer varied greatly. It can be assumed that this variation, although blocked due to the experimental design, affected the results of the study. For example, one of the organic farmers at a high altitude was scored significantly lower than the others in farmer-led management and, as a consequence, the plants performed poorly on this farm. On the other end of the spectrum, an organic farmer at a low altitude displayed very advanced management practices; on this farm, plants developed quickly and grew to be very large and productive.

Farmer management has an impact on the likelihood that the farmer will adopt new varieties. The higher the level of farmer interest and participation in a PVS project, the more likely the farmer is to adopt new crops. When farmers lack motivation or the knowledge to properly manage crops, the true potential of new varieties cannot be recognized and therefore may not be appreciated (Joshi and Witcombe 1996).

Results from this study showed that increased varietal choice gave individual coffee farmers in Costa Rica more possibilities to increase the productivity of their farms more than when they had access only to current commercial varieties. Different varieties had different farmer-preferred traits that are useful in different situations. The most successful varieties, according to farmers as well as to morphological characterization and evaluation data, changed in different environments and under different types of management. This illustrates that if homogenous solutions are offered to farmers, such as one particular tomato or sweet pepper variety being offered to multiple farmers in different environments and with different motives, the performance of the crop may be low and thereby may discourage farmers from diversifying their farms. Without a wide range of varieties to choose from, farmers lack opportunity to see the true potential of vegetable diversification within the farm (Jäger *et al.* ;Ceccarelli 1994).

Many studies report the utility of using PVS in on-farm trials for selecting varieties that perform well in diverse environments and meet farmer criteria (Witcombe *et al.*

1996;Friis-Hansen and Sthapit 2000;Atlin *et al.* 2001;Araya-Villalobos and Hernández-Fonseca 2006;Oluoch *et al.* 2009;Gautam *et al.* 2013;Ciancaleoni *et al.* 2014) We applied participatory evaluation and PVS in the current study to allow farmers to choose specific tomato and sweet pepper varieties that have more preferred traits and that have the potential to maximize crop performance.

The use of weighted farmer scores to compare varieties demonstrated that applying weighted values is highly important in participatory evaluation because preferences can change drastically based on the weights assigned to each farmer-preferred trait. By comparing the weighted farmer scores to the farmers' overall scores for each variety, it was seen that the original assumption may be true: when farmers are evaluating varieties overall, they are not taking into consideration the weighted importance of each trait they identified as being important prior to the evaluation.

This study revealed that while both farmers' scores and characterization data identified the commercial tomato variety as most successful with respect to traits sought out by the commercial market, CATIE accessions and AVRDC varieties were most successful for all other farmer=preferred tomato traits.

According to farmers' scores for tomato varieties, the improved commercial variety scored highest for traits such as fruit weight and good fit for market. Characterization data demonstrated again that the commercial tomato variety had the highest fruit weight. CATIE accessions and AVRDC improved varieties dominated all other farmer-preferred traits according to both farmer scores and characterization data. For example, AVRDC2 had the highest resistance to all pest and disease categories for tomatoes according to characterization data, and CATIE random2 to all tomato pests and diseases according to farmer scores. CATIE random and CATIE select accessions were repeatedly scored as the most preferred varieties by farmers due to their favorable traits pertaining to fruit color, flavor, fruit sweetness, fruit juiciness, high yield, meaty flesh, fruit firmness and plant height.

The same phenomenon seen in tomatoes held true for sweet peppers. Farmers scored improved varieties, Commercial 1 and AVRDC2 as having the best fruit size and fruit length. Characterization data again demonstrated that the improved varieties, both commercial and AVRDC, dominated fruit size categories: fruit weight, fruit width and fruit length. However, CATIE select and CATIE random accessions were scored highest by farmers for traits such as fruit that lasts longer after harvest, good flavor, fruit firmness and desirable fruit color. Characterization data showed that CATIE select varieties had the highest resistance to pests and diseases in general (CATIE select3) as well as to *Cercospora* (*C*ATIE select4), while commercial varieties had the highest resistance to *Psedomonas* (Commercial1), one of the most detrimental diseases for sweet pepper crops.

Although the improved varieties, both commercial and AVRDC, performed better with regard to commercially valued traits, CATIE accessions and some AVRDC varieties performed and were scored high by farmers for other traits of interest. Not all farmers were interested in varieties that displayed the best results for commercial characteristics. Some farmers, especially organic, were searching for characteristics apart from these commercial characteristics, in varieties that can be used for other purposes, such as value-added products.

Phytophthora is one of the most detrimental diseases for tomato crops. The disease can cause significant reduction in yields as well as severe damage to the foliar and fruit part of the plant (Oluoch et al. 2009;Quesada-Ocampo and Hausbeck 2010). According to characterization data, AVRDC2 had the highest resistance to both *Phytophthora* and *Alternaria.* However, when comparing resistance across groups, the CATIE random group of accessions had the highest resistance to *Phytophthora* and *Alternaria*.

This result displayed the importance of environmentally specific variety selection. When comparing results among groups (CATIE select accessions, CATIE random accessions, AVRDC varieties and commercial varieties), we got one result, and when we compared among specific varieties, we got another result. This is why on-farm variety analysis is so important: generalized varietal selection may not always be appropriate for every environment and may leave out interesting and highly useful results (Ceccarelli 1994).

As climates continue to change, especially in the tropics, new varieties having higher resistances will be needed. Both *Phytophthora* and *Pseudomonas*, for example, develop more quickly and more severely in wet climates in tomato and sweet pepper crops, respectively. Often, new and improved vegetable varieties are created using genes from traditional varieties that have specific characteristics, such as increased pest and disease resistance (Ebert 2014). Moreover, results from this study and many others demonstrated the potential of characterized and promising accessions from genebank collections in tropical heterogeneous environments because they often are more preferred by farmers than available commercial varieties and display better performance in many farmer-preferred trait categories. (Mulatu and Zelleke 2002;Quesada-Ocampo and Hausbeck 2010;Carvalho *et al.* 2013;Gautam *et al.* 2013;Ebert 2014).

Significant interactions between variety and altitude as well as between variety and type of management were found in farmer scores. Farmers at different altitudes and using different types of management preferred different sweet pepper varieties. These preference differences may have been due to diverse farmer-preferred traits at different altitudes or under different types of management. They may also have been attributed to better performance, measured by scientific descriptors, of certain accessions or varieties at different altitudes or under different types of management. Regardless, these difference again highlight the importance of considering genotype-environment interactions to find the most appropriate improved varieties or traditional accessions for diverse environments. Other studies have found similar results (Ceccarelli 1994;Atlin *et al.* 2001;Mulatu and Zelleke 2002;Bertero *et al.* 2004;De Swart *et al.* 2006).

Characterization data also illustrated how altitude and type of management influenced which varieties were most successful. The varieties that were most resistant to the different pests and disease changed with altitude and under both types of management. For example, the AVRDC2 tomato variety appeared to be the most resistant to tomato pests and diseases in general when a general analysis was done, without considering altitude and management. However, when these two variables were considered, CATIE random2 was the most resistant to pests and diseases in general under conventional management, and CATIE select5 was most resistant to pests and disease in general at high altitudes.

There are differences between which varieties were preferred by farmers and which demonstrated the most potential according to characterization and evaluation data. Farmer preferences were dominated by CATIE select and CATIE random accessions, while scientific characterization identified most frequently improved AVRDC varieties as successful. Although it was observed that scientists and farmers were searching for the same characteristics in varieties, the differences in results may have been because farmers and scientists have distinct criteria for scoring varieties. Oftentimes, farmer motives and scientific motives are different, explaining why the two techniques to evaluate varieties yielded differing results. These differences highlight the importance of including farmers' preferences in varietal evaluation. Other studies have also found that farmers' preferences are very useful when selecting varieties for further use and improvement (Witcombe *et al.* 1996;Bacon *et al.* 2005;Witcombe *et al.* 2005;Ceccarelli y Grando 2007;Halewood *et al.* 2007).

In general, it was difficult to say whether improved varieties (AVRDC and commercial varieties) or genebank accessions (CATIE accessions) had more potential for farm diversification. Both improved varieties and genebank accessions were useful for diversification, and their potential was dependent on site-specific biotic and abiotic factors. Increased varietal choice allows farmers to choose for themselves whether they want to plant improved varieties or genebank accessions. When farmers have access to a wider range of intraspecific diversity, it is more likely that they will find varieties that fit their specific motives and environmental conditions. This can lead to a more extensive interest and use of interspecific diversification, bringing the many benefits of both types of diversification to the farm (Van Bueren *et al.* 2005;Lin 2011).

Although field studies in areas with specific conditions can be carried out to determine the varieties or variety groups best to recommend, this type of generalization can greatly decrease the effectiveness of on-farm diversification and neglect specific genebank accessions of high potential. It is recommended that individual farmers be given access to packets of options that contain different types of varieties and accessions, so each can choose for himself or herself what varieties are best for the farm.

The study revealed that the coffee farmers enjoyed this participatory evaluation and PVS because it gave them the chance to learn in an interactive environment and to discover new tomato and sweet pepper varieties of high quality and great potential that are not available in today's commercial marketplace. All of the farmers explained that it is currently very hard to find unique varieties with characteristics adapted to changing climate conditions; for example, many mentioned that it is nearly impossible to find tomato and sweet pepper varieties with sufficient pest and disease resistance to confront the pests and diseases that exist today. All of the farmers said that with the new varietal selection choices from the current project, they felt more motivated to continue seeking new diversification options for the farm.

Participatory evaluation has many benefits as well as specific drawbacks. Lack of access or knowledge of access to a diverse selection of vegetable varieties negatively affects farmers' efforts to diversify their farms (Carvalho *et al.* 2013;Bioversity International 2014). All farmers in the current study confirmed this finding through their frustration with their current access to a narrow range of commercial varieties. Participatory evaluation is a way to bring diverse material to farms so that the farmers have access to a wide range of varietal options to find those varieties that perform best for their specific conditions. When farmers have the resources they need for intraspecific diversification, interspecific diversification becomes more appealing (Lin 2011). After the current study concluded, most of the farmers felt more motivated to contact CATIE for new varieties in the future.

On the other hand, participatory evaluation is a time- and resource-intensive process. As seen in this study, the level of experience in vegetable crop management most likely influences study results. Participatory evaluation with farmers who are not motivated or who lack sufficent knowledge to carry out the evaluation adequately is inefficient (Araya-Villalobos and Hernández-Fonseca 2006). One suggestiont to improve the effectiveness of participatory evaluation is to plant a larger number of new varieties and accessions with a smaller group of farmers that have more experience. A larger group of farmers can be invited to the study plots to participate in the evaluation at the end of the study to capture the farmers preferences. This could reduce costs and focus efforts on finding a wider range of promising varieties while working with dedicated farmers who will develop the plants to their full potential.

Another aspect of participatory evaluation that should be considered is the end motive of each farmer for diversification. While half of the farmers in the current study were interested in new varieties for a wide range of activities, such as value-added products and home cooking, the other half were only interested in new varieties that would be accepted by the commercial market. It could be useful to collect information regarding motives before starting a participatory evaluation and include different study groups that represent the different types of producers (Jäger *et al.*).

Participatory evaluation is an important tool for bringing diverse genetic matieral directly to farms. Generally, germoplasm material is first sown and improved at research stations and then given to farmers to plant on their farms. However, if genebank material is given directly to the farmers, farmers can improve the material themselves according to specific farmer criteria as well as contribute to the distribution of genetic diversity within local seed systems (Jäger *et al.* ;Carvalho *et al.* 2013;Bioversity International 2014).

In this study, genebank material from tomato and sweet pepper collections from CATIE was given directly to the farmers. These genebank collections included landraces and heirloom varieties, some of which showed good performance for the farmer-preferred traits defined in the study and allowed farmers to see the potential of genebank materials in their own farm environments and under their specific management techniques. Each individual was able to choose specific varieties better adapted to that specific farm, using the genetic material more efficiently.

However, in order for this direct use of genebank material to be sustainable, the structure and efficiency of local seed systems need to be considered. In this study, seven of the eight farmers were saving seeds from the new varieties by the end of the study. However, none of the farmers had adequate systems for saving seeds because they have become accustomed to buying commercially available seed year after year. Without appropriate seed saving, the introduction of new genetic material to farms will not be a sustainable effort. Capacity building is necessary so that farmers can not only recapture the importance of seed saving but also learn easy on-farm techniques for saving seeds appropriately.

2.5 Conclusion

Increased varietal selection for farmers is useful because it gives farmers with different motives a wider range of options, increasing the probability that they will find varieties and accessions that fit their specific needs and specific environments. Oftentimes, generalized variety selection for generalized environmental scenarios can leave out important varieties and accessions of high potential. By taking into consideration altitude and type of management, along with other farm-specific factors, successful tomato and sweet pepper varieties can be selected more effectively.

It is not easy to say whether improved varieties or genebank accessions are most useful for farm diversification. Rather, it is important to encourage the use of improved varieties as well as the direct use of genebank accessions in order to determine the most successful varieties at the farm level.

For a more efficient use of accessions, farmers should be connected directly to genebanks. Apart from this direct link, nongovernmental and governmental organizations that are able to multiply seed materials should also be connected to the diverse genetic resources in genebanks. This will allow them to offer a wider selection of varieties to farmers during capacity-building activities or other initiatives.

Government subsidies would also help encourage on-farm diversification. By offering subsidies to farmers willing to experiment with diversification, the farmers’ risk decreases and they will feel more motivated and secure in trying new diversification activities, such as planting lesser known varieties.

By using participatory evaluation and morphological characterization to evaluate a diverse array of varieties and accessions, more specific varietal recommendations can be made taking into consideration genotype X environment interactions. Although farmer-preferred traits are similar to the traits being characterized by scientists, farmers often have different criteria that result in the identification of different varieties as most successful. For this reason, participatory varietal selection is not successful without the combined effort of scientists and farmers (Almekinders *et al.* 2007).

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