TROPICAL AGRICULTURAL RESEARCH
AND HIGHER EDUCATION CENTER

Education Division

Graduate School

How does increased vegetable varietal choice influence coffee farmers' on-farm diversification strategies in the face of changing climate conditions?

Lindsey Allison Hethcote

Thesis submitted to the Graduate School as a requirement to qualify for the degree of

Master of Science in Agroforestry and Sustainable Agriculture

Turrialba, Costa Rica

2016

This Master's thesis has been accepted in its present form by the Division of Education and the Graduate School Program of CATIE and by the advisory committee of the student, considering that it fills the requirements necessary for the student to present the final defense as well as participate in the final exam.

***MAGISTER SCIENTIAE* IN AGROFORESTRY AND SUSTAINABLE AGRICULTURE**

SIGNATORIES:

Maarten van Zonneveld, Ph.D.
Thesis co-director

William Solano Sánchez

William Solano, M.Sc.
Thesis co-director

Nelly Vásquez, Ph.D.
Member of the Advisory Committee

Ernesto Méndez, Ph.D.
Member of the Advisory Committee

Francisco Jiménez, Dr. Sc.
Dean of the Graduate School

Lindsey Allison Hethcote
Candidate

Dedication

To smallholder farmers in Central American seeking strategies to diversify their farms and to scientists working toward a more sustainable use of agrobiodiversity. May this work contribute to the livelihoods of the farmers and the advancements of the scientific community.

Thank you to Bioversity International, CATIE, Hivos International and AVRDC for their extensive support, logistically and financially, for the fieldwork involved with this master's thesis project.

Acknowledgments

I would like to acknowledge the people and institutions that have contributed to my work toward this Master of Science degree and to offer my profound thanks for their support.

Maarten van Zonneveld of Bioversity International and William Solano of CATIE for their continued support throughout this project, as not only co-directors but also team members

The other members of the committee, Nelly Vasquez and Ernesto Mendez, for their guidance and recommendations

AVRDC, the World Vegetable Center, for its extensive support for my fieldwork

Hivos International for the support provided for fieldwork necessary for my thesis

Organization of American States (OAS), whose scholarship made my studies as a master's student possible

My mom, dad, stepmom, grandmas, grandpas, aunt, uncle and other family members for their moral support and constant encouragement throughout my two years at CATIE

My wonderful friends at CATIE who have filled me with joy and laughter when I most needed it

My wonderful friends in the States who were with me every step of the way

A very special person who appeared in my life unexpectedly at CATIE and who has shown me unconditional support and friendship when I have most needed it

Those who helped me tirelessly with my fieldwork (Manrique Gonzalez, Dagoberto Arroyo, Alexander Salas, Jairo Mendez, Jose Brenes and Erlindo Navarro)

The CATIE Biostatistics Unit (Fernando Casanoves, Sergio Vilchez and Alejandra Ospina) for assistance with processing and data analysis

All of the staff of CATIE's Graduate School (Jeannette Solano, Ariadne Jimenez, Aranjid Valverde, Cynthia Mora, Alfonso Marin, Marta Gonzalez and Noily Navarro)

All of the professors of CATIE Graduate School for their expertise and patience

The Ministry of Agriculture and Livestock (MAG) of Costa Rica for logistical support with my fieldwork

Irene Garcias for her guidance and expertise

All of the coffee farmers involved in the project for their dedication and enthusiasm

Contents

Figures

Tables

Acronyms

AVRDC	The World Vegetable Center
CATIE	Tropical Agricultural Research and Higher Education Center (Centro Agronómico Tropical de Investigación e Enseñanza)
ICAFE	Costa Rican Coffee Institute
IPCC	Intergovernmental Panel on Climate Change
IPGRI	International Plant Genetic Resources Institute (Bioversity International since 2006)
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
MTA	Material Transfer Agreement
PPB	Participatory plant breeding
PVS	Participatory varietal selection
SAPM	Strategic Action Plan to Strengthen the Conservation and Use of Mesoamerican Plant Genetic Resources in Adapting Agriculture to Climate Change
SMTA	Standard Material Transfer Agreement

Abstract

Crop diversification strategies are considered promising for Central American coffee farmers who are 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 be a constraint to 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 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 a few commercial varieties currently available in Costa Rica. 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 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 and evaluation data also shows a 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 and evaluation data demonstrates that farmers often indicate varieties having the most potential to diversify farms that vary from those indicated in the agronomic evaluation. 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 farmers themselves. Farmers' opinions in 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.

Resumen

Las estrategias para la diversificación de cultivos son prometedoras para los agricultores de café en América Central, quienes buscan soluciones para enfrentar las condiciones del clima que están en constante cambio. Los cultivos de hortalizas son promisorios para la diversificación de sistemas de café y otros sistemas por su alto potencial para generar ingresos y combatir la inseguridad alimentaria de los agricultores. Sin embargo, una selección limitada de variedades puede contribuir a una adaptación débil y eventualmente una restricción para introducir estos cultivos. Se prevee que con un aumento en la disponibilidad de variedades de hortalizas, específicamente tomate y chile dulce, los agricultores pueden mejorar sus decisiones a la hora de diversificar sus fincas, tomando en cuenta las condiciones ambientales y de manejo. Este estudio emplea una evaluación participativa con ocho agricultores de café en Turrialba, Costa Rica en dos alturas y bajo dos tipos de manejo diferentes (convencional y orgánico), así como la caracterización y evaluación morfológica de una gama de diversas variedades de tomate y chile dulce (AVRDC, CATIE, y variedades comerciales), para determinar si un aumento en la selección de variedades disponibles mejora las estrategias de diversificación agrícola ante el cambio climático. Estas variedades se seleccionaron del banco de germoplasma de CATIE y del programa de mejoramiento de AVRDC; su desempeño se comparó con las variedades comerciales disponibles en Costa Rica. Tanto la evaluación participativa como la caracterización y evaluación morfológica, las variedades comerciales mostraron características buscadas en el mercado comercial, mientras que las variedades de CATIE y AVRDC mostraron otras características preferidas por los agricultores. Tanto la altitud como el tipo de manejo influencian las preferencias de variedades de los agricultores, ilustrando la importancia de una selección más amplia de variedades para los agricultores de café que siembran en diversos entornos. Los datos de caracterización y evaluación muestran una interacción significativa entre la variedad y la altitud, así como la variedad y tipo de manejo. Una comparación de las variedades más exitosas definidas por los agricultores y las variedades de acuerdo a los datos de caracterización y evaluación, demuestra que los agricultores indican frecuentemente diferentes variedades como las que tienen mayor potencial para diversificar la finca. Sin el uso de métodos, como la evaluación participativa, para incluir las preferencias de los agricultores en una selección de variedades, muchas veces pueden ser promovidas algunas variedades que aparecen más satisfactorias, pero en realidad no son preferidas por el agricultor. Las opiniones de los agricultores en el presente estudio, muestran que la evaluación participativa de variedades utilizadas ha sido una herramienta eficaz para ayudar a identificar diferentes variedades que tienen un alto potencial para diversificar la finca.

1. Chapter 1: Introduction and general summary of thesis

1.1 Justification and importance

Latin America has a long history of perennial mono-cropping, including palm oil, cacao, coffee and rubber. Although there are many benefits to these systems, such as high economic returns, there are also consequences, mainly increased economic and environmental risks due to their homogeneity (Alvim 1980).

In Central America, the effects of climate change on perennial systems will be most severely felt by smallholder farmers throughout the coffee sector. The extreme climate changes predicted by the Intergovernmental Panel on Climate Change (IPCC) will drastically alter the regions in which coffee can be successfully produced. The organization predicts that temperatures in Central America will increase between 1 and 2 degrees Celsius and precipitation will decrease by as much as 30% by the end of the 21st century (Davis *et al.* 2012). Nicaragua, for example, is supposed to see a mean annual temperature increase of 2.3 degrees Celsius and a 5% decrease in precipitation by 2050. (Baca *et al.* 2014).

Arabica coffee production is expected to be negatively affected at low altitudes where temperatures are expected to increase the most. Changes in temperature and precipitation will continue to displace coffee farmers. Central America in general will see a shift in optimal coffee-growing elevation from 1,200 meters to 1,600 meters by 2050 (Baca *et al.* 2014).

Central American coffee farms that lack diversity will be more vulnerable, environmentally and economically, to these climate changes than diverse systems. The less functional diversity that an agroecosystem has, the more vulnerable the biotic characteristics of the system are to biotic and abiotic changes (Lin 2011;Ebert 2014). In addition to changing climates, Central American coffee farms face increasing threats from pests and disease. Oftentimes, the narrow genetic base of a homogenous coffee system raises the probability of absolute crop failure, leading to food insecurity and sometimes debt (Di Falco and Perrings 2003;Caswell *et al.* 2014).

Apart from the environmental risks associated with coffee systems, economic risks are also apparent. Both large and small producers often face issues with low economic income during the initial phases of a coffee system, as well as sporadic income throughout the year. Studies have shown that because coffee farmers only receive income two or three times a year from their coffee crops, those who do not also have other crops for consumption and sale suffer food insecurity between peak coffee harvests (Morris *et al.* 2013;Bacon *et al.* 2014;Caswell *et al.* 2014). Caswell *et al* (2014) found that seasonal hunger may be prevalent from one and eight months per year for coffee farmers who lack diversity on their farms.

In recent years, researchers working with coffee producers in Central America have begun to explore how diversification can lead to more stable and sustainable livelihoods for rural farmers (Flores 2002;Caswell *et al.* 2012;Morris *et al.* 2013;Baca *et al.* 2014;Bacon *et al.* 2014;Caswell *et al.* 2014). Sustainable livelihood refers to “the resilience of households to environmental, economic, and social stresses and shocks” (Morris *et al.* 2013).

Diversified systems are more sustainable because they provide diverse sources of income, a variety of food for consumption and enhanced functional diversity that allows a system to be more resilient against climate and human-induced changes (Eakin *et al.* 2006;Lin 2011;Caswell *et al.* 2014). Species diversification is often recommended to stabilize production and income, but little research is being done on the identification and potential of under-researched seed material of different crops for diversification (Zonneveld *et al.* 2014)

Intraspecific diversity provides overlaps in the functional capacity of different varieties (Lin 2011;Ebert 2014). Greater diversity within a system creates spatial and temporal heterogeneity, which in turn enhances resilience to stresses impressed on the system, both environmental and economic. Successful pest and disease suppression is often found in more diverse systems due to the decrease in crop-specific pests and disease that can lower production or devastate crops. Diversity also creates a buffer against other effects of climate variability (Di Falco and Perrings 2003;Ebert 2014;Bioversity International 2014). Intraspecific diversification can open up new or unknown niche markets for farmers lacking economic sustainability (Zonneveld *et al.* 2014).

Genebanks hold many accessions containing a range of genetic and phenotypic variability that have the potential to be interesting and useful for crop diversification across different environments and for different farmers’ interests. It can be expected that some of these accessions have high nutritional values, while others have developed advanced tolerances to abiotic and biotic stresses or are recognized for their yield stability (Eagles and Lothrop 1994;Hammer and Diederichsen 2009;Ciancaleoni *et al.* 2014;Ebert 2014). This diversity is a valuable source for breeding but could also have great potential for direct selection of promising materials.

Information regarding biotic and abiotic factors of systems coupled with selection by farmers of successful genotypes and participatory characterization of varieties in different environments has the potential to help discover varieties with interesting characteristics and values not yet exploited (Friis-Hansen and Sthapit 2000;Halewood *et al.* 2007;Ciancaleoni *et al.* 2014;Bioversity International 2014).

There have been many success stories about using participatory variety selection (PVS) and participatory plant breeding (PPB) of diverse genetic material for a better use of genetic material on farms (Witcombe *et al.* 1996;Almekinders *et al.* 2007). There is also evidence showing that PVS can be challenging. Oftentimes, researchers and farmers have different motives in mind, making it difficult to agree on project details and outcomes. A wide range of aspects affecting a PVS, such as various social and economic aspects, may not be taken into account and may negatively affect the project’s outcomes (Bacon *et al.* 2005).

It would be useful to include PVS in the selection of genebank material for the diversification of farms. By including farmers, their opinions, traditional knowledge and site-specific information for their farms, choices on accession selection can be made that are more effective than conventional variety selection.

One particular challenge to the enhanced used of genebank material is the successful development of mechanisms that facilitate farmers' access to genebank material that matches their interests (Witcombe *et al.* 1996;Friis-Hansen and Sthapit 2000;Almekinders *et al.* 2007;Ceccarelli and Grando 2007;Halewood *et al.* 2007;Bioversity International 2014). Currently, farmers lack crucial knowledge about how and where to access genebank material and information, making it extremely difficult for them to effectively use diverse varieties and accessions. Lack of collaboration between national, international, local, governmental and nongovernmental organizations makes it hard to diffuse the genetic material (Almekinders *et al.* 2007).

Access to genebanks, along with the phenotypic information associated with each accession, is pertinent to farmers (Ebert 2014). The genebank at CATIE (Tropical Agricultural Research and Higher Education Center) holds more than 5,704 accessions of 187 species, making it a very valuable resource both nationally and internationally (Engels *et al.* 2006). Although CATIE's resources are recognized at the institutional level, many local actors do not take advantage of this material (Vasquez and Solano 2014).

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), Plant Treaty for short, aims to enhance the access to and use of accessions from genebank collections. This is especially important under changing climates scenarios where it is essential that farmers and breeders have access to varieties that can make their agricultural systems more resilient to climate change (FAO 2009). The Plant Treaty includes a list of crops from which parties have agreed to share materials, following a Standard Transfer Material Agreement (STMA). Tomatoes and peppers are not included on this list, but a few genebanks, including those of CATIE and AVRDC (the World Vegetable Center), have put their collections of these crops under FAO's Multilateral System, which facilitates access via an STMA.

This study proposes the participatory use and evaluation, according to specific farmer preferences, of genebank accessions and improved varieties to diversify coffee farms in Costa Rica in order to enhance economic and environmental resilience to effects of varying climate conditions.

1.2 Objectives

1.2.1 Main objective

Understand the role of increased varietal choice and participatory varietal selection in motivating producers to adopt new crops for diversification activities on their farms.

1.2.2 Specific objectives

- Identify which crops are of most interest to farmers for on-farm diversification activities
- Identify the key traits farmers look for when selecting vegetable varieties

- Understand how under-researched genebank material can correspond to specific farmer interests in different environmental conditions compared with improved varieties and available commercial varieties
- Evaluate the performance of the selected materials in different environments
- Consider the role of participatory evaluation in helping farmers identify more interesting crop varieties for farm diversification

1.3 Literature review

1.3.1 Current state of coffee farmers in Central America and diversification as a solution to the crisis

Concentration on the coffee sector in Central America in the latter half of the 20th century brought about national subsidy support that encouraged producers to turn to coffee mono-cropping. However, due to historically low prices in the international coffee market since the coffee crisis in 2000, coffee producers in Central America have been left with lower incomes and therefore very vulnerable production systems that have lower resistance to fluctuations in economic and environmental changes (Eakin *et al.* 2006).

A recent survey of 500 smallholder coffee farmers in four countries in Central America showed that 63% of the interviewed producers struggled to meet basic food needs during at least one period of each year. The vulnerability of small-scale coffee farms is attributed to multiple market factors, including market deregulation resulting from the fall of the International Coffee Agreement in 1989, oversupply of coffee in the international market and monopolistic control by multinational coffee companies that have forced coffee prices to a historical low. From 2000 to 2001, the "green bean" crisis forced revenues for Central American coffee farms to drop 44%, and most of the producers affected by this are still struggling to recover (Morris *et al.* 2013).

Since the collapse of the international coffee market, countries dominated by smallholder coffee production have continued to see negative effects. Apart from the rapid fall in prices, changing environmental conditions have continued to put even more pressure on smallholder production systems. Decreased rainfall and increased temperatures have augmented the incidence of pests and diseases. Lower incomes have also made it harder for smallholders to buy the fertilizers and pesticides needed to properly manage their coffee, also increasing pest and disease incidence. Studies done by the Costa Rican Coffee Institute (ICAFE) have shown the impacts of climate changes on different coffee production regions of the country (ICAFE 2014).

The incidence of the coffee borer beetle and coffee rust has increased in Costa Rica due to changing climate conditions. In 2013, it was found that more than 95% of the area dedicated to coffee production in the country was negatively affected by the coffee-berry borer. The coffee harvest in 2013 in Costa Rica decreased by 69.8% and then again in 2014 by 18.6 % due to the increased incidence of coffee rust (ICAFE 2014).

According to IPCC climate predictions, temperature increases and as much as a 30% reduction in precipitation by 2050 will continue to limit the areas suitable for Arabica and Robusta coffee production. The changes will put many current coffee-growing regions out of the optimal and absolute ranges for coffee production (ICAFE 2014).

Table 1. Current optimal and absolute conditions for Arabica and Robusta coffee

	Arabica				Robusta			
	Optimal		Absolute		Optimal		Absolute	
	Min	Max	Min	Max	Min	Max	Min	Max
Temperature (°C)	14	28	10	34	20	30	12	36
Rainfall (mm/year)	1,400	2,400	750	4,200	1,700	3,000	900	4,000
Soil pH	5.5	7	4.3	8.4	5	6.3	4	8

Source: (ICAFE 2014)

As coffee production by smallholder farmers dependent on the crop continues to decrease due to climate change and international prices remain low due to market factors, livelihoods will become more vulnerable due to decreased economic income and food security. This vulnerability in Latin America has received much attention since the global coffee crisis in 2000 (Bacon 2005;Morris *et al.* 2013).

Table 2. Summary of food insecurity in coffee-growing regions

Region	**Study size**	**Study type/research date**	**% experiencing food insecurity**	**Reference**
Nicaragua, Guatemala El Salvador, Mexico	469 households	Stratified survey, 2004—2005	63% struggling to meet basic food needs	Méndez, VE *et al,* 2010
Northern Nicaragua	177 households	Participatory Action Research (focus groups, surveys and long-term case study), 2006	69% unable to meet basic food needs at some point	Bacon, CM *et al,* 2008
Nicaragua, Mexico, Guatemala	179 households	Household level surveys and interviews (unpublished), 2006–2007	31% in Mexico, 44% in Nicaragua and 61% in Guatemala unable to meet food needs at some point in the year	Fujisaka, S (CIAT), 2007
Western El Salvador	29 households	Semi structured interviews, 2008	97% unable to meet basic food needs at some point	Morris, K, forthcoming
Northern Nicaragua	256 households	Stratified survey and household interviews, focus groups, anthropometric measures (unpublished), 2009-2010	82% unable to meet basic food needs at some point	Bacon, CM *et al,* unpublished
Northern Nicaragua	87 households	Household surveys and interviews stratified by participation in a food security initiative, 2009	100% unable to meet food needs at some point during the year; average of 3 months of food insecurity/year	Pino, M, unpublished

Pico Duarte region, Dominican Republic	41 households	Participatory Action Research, 2011	82.9% have trouble covering basic food necessities	Gross, L, 2011

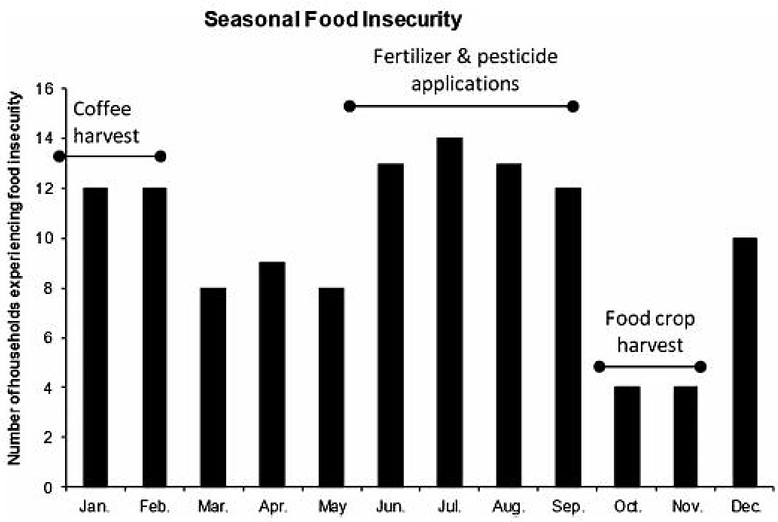
Source: (Caswell *et al.* 2012)

International organizations and academics continuously search for solutions for smallholder coffee farmers in Central America; among the solutions, diversification is often suggested as a way to mitigate the vulnerability of the systems (Flores 2002;Eakin *et al.* 2006;Caswell *et al.* 2012;Morris *et al.* 2013;Baca *et al.* 2014;Caswell *et al.* 2014).

Diversification of coffee farms has already started, but present-day commercial varieties of vegetable crops are often used. Morris et al. (2013) showed in a study in 2008 with a group of coffee farmers in El Salvador, that of the 29 farms surveyed, all had planted maize and beans as subsistence crops, and 34% of producers had planted other vegetables for sale and occasional consumption. All of the producers surveyed had planted conventional varieties of maize, beans and other vegetables and were applying chemical fertilizers and pesticides to increase yield; yet they were having difficulties affording these expensive chemicals (Morris *et al.* 2013).

Food plots within the coffee farms provided on average 54% of the household food throughout the year. Because the farmers were so dependent on their staple vegetable crops for their own consumption, most explained that the risk of trying new crops or growing crops without chemical inputs was too high, and that if the system failed or produced less, their families would experience even more hunger (Morris *et al.* 2013).

Other studies with coffee farmers throughout Central America have shown that, on average, 40–70% of food consumed by the household comes from crops produced within the farm. However, the more diversity found on a farm, both within trees species and vegetable species, the less food insecure the family reported itself to be throughout the year. (Caswell *et al.* 2012;Morris *et al.* 2013;Caswell *et al.* 2014).



Source: (Morris *et al.* 2013)

Figure 1. Seasonal food security experienced by coffee-producing households in El Salvador

Figure 1 shows that directly following harvest of the food crop (December–February), the producers growing only coffee and staple crops of maize and beans were still food insecure due to lack of extra income to buy other foods such as rice, chicken, eggs, sugar, vegetables and cooking oils. The seven households that grew a variety of vegetables in their food plots, including tomatoes, peppers and cabbage, in addition to their maize and bean crops, reported that they were not food insecure during January or February (Morris *et al.* 2013).

This study, as well as other similar studies, has concluded that to improve the livelihoods of small-scale coffee farmers, the role of household food production should be emphasized, both for consumption as well as sale. (Caswell *et al.* 2012;Morris *et al.* 2013;Caswell *et al.* 2014).

Mendez (2010) showed that coffee farmers interviewed throughout Central America who reported having more sources of income were also those who were able to meet their food needs. Households that did not report food shortages reported an average of 2.5 income sources, while those that did have food shortages reported 2.2 sources of income, on average.

However, diversification with commercial varieties may not be the solution for coffee farmers. During interviews with three coffee producers in Turrialba, Costa Rica, in 2014, the same issues were reported that Morris found in 2008 when Central American coffee farmers tried to diversify their farms with food crops. These producers in Turrialba reported that they had tried to plant commercial varieties of food crops such as tomato and sweet pepper but that the success of the crop required high chemical inputs that were too expensive to justify continued planting. The producers said they were losing money on the food crops; they found it better just to stick with their coffee plants (Hethcote 10 Nov 2014).

One producer in particular, from Alto Varas, Turrialba, Costa Rica, said that 25 years ago, everyone in his town was planting tomato and pepper crops. He said the climate used to be perfect for the crops, and many producers had much success with them. Now that the climate has changed and the community experiences longer periods of drought, no one is planting tomatoes or peppers. He said the present-day commercial varieties the producers are using require so much pesticide, due to an increase in pest incidence related to increased temperatures, that most producers choose not to plant them, either for economic reasons due to high prices of inputs or because of the negative effect of the chemicals on the environment (Hethcote 10 Nov 2014).

This same farmer now plants only landrace varieties of food crops such as tomatoes and peppers for consumption, claiming that their natural resistance allows him to produce a small amount of fruit with no chemical inputs (Hethcote 10 Nov 2014).

These interesting, if anecdotal, observations bring up several questions for further research on the potential of increased varietal choice, more specifically using landraces that are currently stored in genebanks, to help farmers sustain their production.

1.3.2 Diversification with intraspecific variation

Crop diversification can be implemented in a variety of forms and at a variety of scales. However, by choosing intraspecific varieties appropriate for certain environments and allowing farmers to make decisions about management and variety selection, adaptation techniques are more likely to be adopted for the long run (Zhu *et al.* 2000). Selection based on site-specific characteristics and farmer preferences are in sync with traditional knowledge and local crop management techniques (Lin 2011).

For successful diversification, genotype and environmental interactions of different varieties must be taken into consideration. Different results come from the use of genetic material in different locations. The behavior of a variety is dependent not only on the genetics of the seed but also on the environmental conditions of the site where it is planted. For example, a study with *Capsicum* species showed that different varieties performed better in different environmental conditions: in general, *C. chinense* varieties are confined to lowland areas, where as *C. pubescence* are only found in highlands, and *C. annuum* are found in a wide range of altitudes (De Swart *et al.* 2006).

Oftentimes, genetic material researched in a controlled environment is applied at the farm level without taking into account the local farmers' preferences or the environmental X genotype interactions. The genetic material that appears to be the most successful in a research station is not always the most successful on the farm. This type of off-site selection process overlooks useful genetic material (Ceccarelli and Grando 2007).

A study done in Syria with different barley varieties showed that locally adapted material found in farmers' fields out yielded the local commercial variety 27–30% when measured in the field. However, when the same locally adapted material was measured in the research station, it showed a significant yield disadvantage to the local commercial variety (Ceccarelli and Grando 2007).

Commercial varieties are created to be successful under certain conditions and therefore often require manipulation of the local environment for the success of the seed. Because commercial seeds require homogenous or manipulated environments, they are often not suitable for farmers living in extreme conditions or for resource-poor farmers who cannot afford inputs to control the environment (Ceccarelli and Grando 2007;Halewood *et al.* 2007;Bonham 2011).

Targeted selection of intraspecific varieties with specific adaptation characteristics can diversify a farm much more sustainably, without the need for strong manipulation of the local site (Ceccarelli and Grando 2007). The genetic diversity held in genebank collections will have individuals that will thrive and others that will naturally fail without the use of external inputs to control the population. Intraspecifically diverse systems will also have better resistance to crop- and site-specific pests and diseases. (Bonham 2011;Ebert 2014).

Knowledge and correct use of this intraspecific variation can lead to diversified farms whose varieties are appropriate for the local environment and provide income and increased food security to farmers throughout the year (Bioversity International 2014).

Apart from the enhanced environmental adaptability of intraspecific varieties, economic benefits also exist. A recent study of *Capsicum* diversity found high potential for diversification of smallholder farms with high value, under-researched crop varieties, such as rarely found and almost unknown varieties of hot peppers. The study explored the interest in under-recognized *Capsicum* varieties and found huge use potential for many varieties. The study predicts that varieties of other New World crops such as squash and tomatoes may also have great potential for diversifying systems within their native distribution range, providing alternative economic options to small-scale farmers (Zonneveld *et al.* 2014).

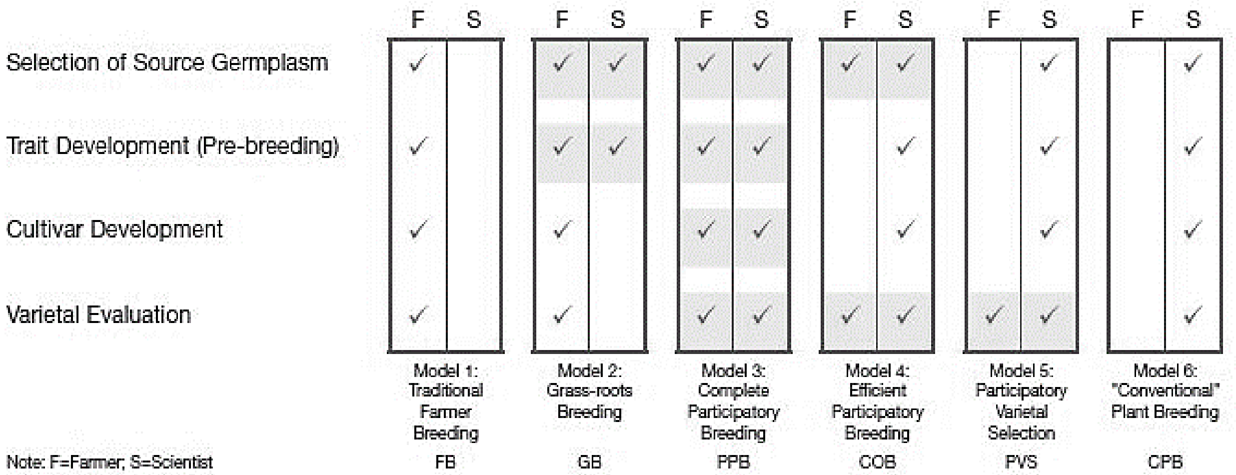
1.3.3 Participatory use of genetic resources according to farmers' needs and preferences

Most diversification projects have only considered the use of conventionally selected seeds that trickle down from research institutions and seed companies to farmers (Ceccarelli and Grando 2007). However it has been shown in various studies that the use of intraspecific material selected by the farmer can be more successful for a long-term sustainable diversification project (Witcombe *et al.* 1996;Almekinders *et al.* 2007;Ceccarelli and Grando 2007). In fact, most farmers in developing countries rely on landrace varieties, showing that farmers have long known the adaptability of these varieties (Mercer and Perales 2010).

The conventional approach to seed improvement and selection does not take into consideration important traditional knowledge and selection criteria that farmers have developed over time through intimate interaction with their land (Almekinders *et al.* 2007;Ceccarelli and Grando 2007). Today, more value is being placed on this traditional knowledge and the importance of farmers' preferences to be able to select varieties that can be sustainably successful in different geographic areas (Friis-Hansen and Sthapit 2000;Ceccarelli and Grando 2007). This concept is commonly known as participatory varietal selection (PVS) (Witcombe *et al.* 1996).

PVS and participatory plant breeding (PPB) programs that are carried out collectively by both farmers and researchers or plant breeders can be a new way in which important genetic material can be used for crop diversification (Halewood *et al.* 2007;Bioversity International 2014). When breeders and researches collaborate with farmers, they can take advantage of the farmers' selection capacity to better understand selection criteria that farmers use every day when selectively breeding on their own farms.

Figure 2 shows the role of the farmer and the scientist in different types of breeding activities for different types of breeding systems.



Source: (Halewood *et al.* 2007)

Figure 2. Role of the farmer and the scientist in different types of breeding systems

After many successful studies of PPB programs, the importance of farmers' preferences has been extensively demonstrated (Witcombe *et al.* 1996;Friis-Hansen and Sthapit 2012;Scheldeman *et al.* 2001;Almekinders *et al.* 2007;Ceccarelli and Grando 2007;Danial *et al.* 2007;Ciancaleoni *et al.* 2014). With locally sourced information, more efficient and selective varieties can be chosen for use. (Danial *et al.* 2007). This type of breeding often takes into account socioeconomic factors as well, and these can have a huge impact on the varieties of seeds used in a community (Ceccarelli and Grando 2007).

The same concept applied in these PPB projects can be applied to selection of material from genebanks (Hethcote 25 August 2014). Farmers know their land and they know what characteristics they want to see in their crops. Often, however, due to lack of access to diverse genetic material, little variety is introduced regularly into their systems. (Witcombe *et al.* 1996).

Table 3 shows the same scheme described above utilized to classify the type of selection system used in the current study.

Table 3. Classification of selection system for current study

	Farmer	Scientist
Selection of source germplasm	X	X
Trait development		
Cultivar development		
Varietal selection	X	X

Researchers and breeders can work with farmers to collect information on their preferences, and then they can suggest genebank material with corresponding characteristics to producers (Almekinders *et al.* 2007).

After conducting a survey to gather a farmer's preferences, one can use germplasm selection tools, such as Explora, created by Bioversity International (formerly the International Plant Genetic Resources Institute, IPGRI), to aid in the selection of materials from a genebank. When individual varieties, or accessions, are entered into the database of a genebank, characteristics of the specific site where they were collected should be recorded, as well as phenotypic information that was recorded with the seed.

However, a main issue with genebank material in general is that many accessions lack essential passport and phenotypic information that would be useful when selecting them for use on farms. Throughout the 70s and 80s, a large amount of genetic material was put into genebanks for conservation, often without this crucial information organized appropriately. In order to effectively use all the material being stored in genebanks today, it must be taken out of the genebank, planted in the field and the characteristics of each accession must be appropriately recorded (Vasquez and Solano 2014)

During this process, farmers' preferences and characterization criteria can be taken into consideration and recorded alongside the basic agronomical descriptors defined for each species. By recording the necessary agro morphological data required by scientists, as well as information from the farmers, the genebank material will be much more useful in the future for collaborative use by both researchers and producers (Halewood *et al.* 2007).

There is a dire need for further research on how phenotypic characteristics of genebank accessions respond to differing environmental conditions and different farmer preferences (Bioversity International 2014). By working alongside farmers and using their preferences to select varieties, farmers will better understand what science can offer them and feel more empowered to make future decisions about accessing diverse genetic material and incorporating it into their farms (Halewood *et al.* 2007).

1.3.4 Farmers' access to important genebank material

The demand for new genetic material with specific adaptive characteristics has already been discussed here; producers are looking for varieties with better ability to change along with the environment. However, farmers' access to genetic material and technical assistance needs to be improved so that germplasm projects involve farmers more in the process of seed selection and breeding (Hethcote 10 Nov 2014).

Another topic of discussion involves producers' direct access to genebank material. Presently, though farmers are technically supposed to have access to genebank material under the ITPGRFA, most do not even know that the genebanks exist. Those who do know about formal genebanks do not have the skills or instruments necessary to access the information. By creating projects where technicians introduce genebank material to producers and explain access to the material, bonds will be created directly between the genebank and producer, with hopes that the producer will continue to explore diverse material from the genebanks in the future (Bonham 2011).

The Strategic Action Plan to Strengthen the Conservation and Use of Mesoamerican Plant Genetic Resources in Adapting Agriculture to Climate Change (SAPM) is a 10-year plan created by Bioversity International. The purpose of the document is to strengthen the conservation, access and use of plant genetic materials in Mesoamerica in an effort to increase both food security and resilience of production systems in the face of varying climates (Bioversity International 2014).

SAPM suggests that a more direct link between genebank material and producers can encourage better use of genetic material. In conventional breeding systems, both improved seeds and traditional accessions are first planted at experimental stations or as part of a research project, and then the select material is offered to the farmers. A more efficient use of genebank material may be possible if the germoplasm is turned over directly to the farmers for evaluation and improvement. Although the process would still involve collaboration between the researcher and the producer, a direct connection between the material and the producer will allow for improvements that are more site-specific, increasing the potential of the genetic material.

There are other working groups and documents intending to enhance access and use of genebank material. These include the ITPGRFA as well as the Nagoya Protocol that focuses on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization (Buck and Hamilton 2011). These groups and plans include initiatives to include farmers' preferences and traditional knowledge to a greater extent in agronomic diversification projects, aiming to increase their interaction with and access to the genetic material (Bioversity International 2014).

Under-researched genetic material can be used most efficiently if it is put back on the farm and managed by producers. Local seed systems in many developing countries are weak and disorganized, lack funding or simply do not exist. In these instances, commercial seeds sometimes are found to be more accessible to smallholder farmers (Bioversity International 2014). However, other studies have found that in developing countries, 90% of the seed used comes from farmers' own selective breeding, not from seed acquired from seed companies. This may mean that the most efficient and useful seed systems are currently taking place at a local scale. In either case, many rural farmers are not aware of their access to germplasm from genebanks, and local systems could benefit greatly from the introduction of intraspecific varieties (Ceccarelli and Grando 2007).

1.4 Main results

When seeds from four horticulture crops—tomato, sweet pepper, squash and hot pepper—were offered to 14 farmers in Turrialba, most expressed interest in tomato (11 farmers) and sweet pepper (eight farmers).

The traits for tomato identified as most important by farmers 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 well fit for the market.

The traits identified as most important by farmers for sweet pepper 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.

Farmer management was evaluated pertaining to specific management indicators defined as most important for the study. The indicators that showed the most variation were management by the farmer as well as several cultural practices required for successful tomato and sweet pepper development. In general, organic farmers had more refined management practices than conventional farmers.

Significant difference in overall farmer scores between tomato accessions and varieties was found ($f = 1.94$, $p = 0.05$, extended and mixed linear models). Overall, farmers' scores among sweet pepper varieties demonstrated that there was also a significant difference between sweet pepper accessions and varieties ($f = 4.51$, $p = 0.0001$, extended and mixed linear models).

The commercial tomato variety (Commercial1) was scored highest by farmers for fruit size as well as good fit for the market. Some CATIE accessions and AVRDC varieties were scored high for pest and disease resistance. Other CATIE accessions scored very high for fruit juiciness, good flavor, sweet fruit and red fruit pulp according to farmers. A CATIE accession (CATIE select5) was scored higher by farmers for yield than the commercial variety (Commercial1). Though common characteristics of commercial varieties include larger fruit size and higher yield, in this study farmers scored a CATIE accession as having better yield.

Sweet pepper varieties illustrated the same phenomenon that was found for tomato varieties. While the improved varieties (Commercial1 and AVRDC2) were most directly related to larger fruit size, CATIE accessions and AVRDC varieties were scored higher in other preferred traits. For example, CATIE accessions (CATIE select1, CATIE random2 and CATIE random3) were scored high for traits such as fruit firmness, fruit color and good fruit flavor. Again, it was found that CATIE accessions and AVRDC varieties scored higher with respect to yield, and in the case of sweet pepper, for resistance to rain as well as pests and diseases.

Three different types of scores were used to evaluate farmers' preferences: 1) overall score per variety, 2) score per variety taking into consideration the farmers' scores for each preferred characterstic and 3) score per variety taking into consideration the farmers' scores for each weighted characterstic. Results show that different accessions or varieties were scored as most successful according to the type of score used.

Using the overall score, results demonstrated that farmers' preferences for tomato varieties remained similar across altitudes and under both types of management. Among sweet pepper varieties, farmers' preferences measured by the overall score changed with different altitudes and under different types of management (H scores of 36.48 and 38.21, respectively; nonparametric, Kruskal-Wallis).

According to characterization and evaluation data, extended and mixed linear models showed that there were significant interactions among variety, altitude and type of management in the majority of the descriptor categories of interest. There were also significant interactions found in both crops among variety group, altitude and type of management. Characterization and evaluation data shows that various varieties and accessions, as well as variety and accession groups, performed better according to the specific preferred traits under both types of management and in each altitude.

According to characterization data, the AVRDC2 tomato variety had the highest resistance to both *Phytophthora* and *Alternaria.* However, when comparing resistance across tomato groups, the CATIE random group of accessions had the highest resistance to *Phytophthora* and *Alternaria*.

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

For sweet pepper varieties, characterization and evaluation data revealed that CATIE select varieties had the highest resistance to pests and diseases in general (CATIE select3), as well as to *Cercospora* (CATIE select4), while commercial varieties had the highest resistance to *Psedomonas* (Commercial1), one of the most detrimental diseases for sweet pepper.

The CATIE random group had the highest resistance in general in low altitudes, and the commercial variety groups had the highest resistance under conventional management. The CATIE select group showed the highest resistance to *Cercospora* at high altitudes and under organic management, while the CATIE random accession group showed the highest resistance for low altitudes and under conventional management. The AVRDC variety group demonstrated 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.

There were notable differences between the accessions and varieties that farmers scored as most successful per trait and the varieties that were most successful per descriptor according to characterization and evaluation data.

All of the farmers in the study said that during their participation in the participatory evaluation, they learned new things and found new varieties with high potential for diversifying their farms. All eight farmers said that they enjoyed the opportunity to work in a diverse team because they felt they could learn more this way. All of the farmers in the study identified tomato and sweet pepper varieties new to them and that they would like to continue growing in their farms. All of the farmers indicated that the current project motivated them to either start or continue diversifying their farm with new crops and new varieties. They said that they had lost motivation for finding adapted varieties because the limited selection of available varieties did not give them many options; however, with the wide range of varieties presented in the current project, they felt more enthusiastic about finding varieties suitable for their environments.

The eight farmers in the study indicated dissatisfaction with the current seed system and that they desire increased access to genetic material. None of the farmers demonstrated an efficient way to properly save seeds on- farm because they have lost the traditional customs of saving seeds and because most of the commercial seeds that they buy are hybrids and cannot be reproduced. All of the farmers said that they would prefer not to be so dependent on the commercial seed system and would benefit from improved access to a greater supply of varieties and accessions that can be saved and reproduced every year on the farm.

Although all of the farmers said participation in this participatory evaluation was worthwhile, they also all gave suggestions for how to improve similar projects. All farmers said that the project should have been planned better and with more time in advance. They all claimed that if they had had more time to prepare the land before the project, the varieties would have developed better.

1.5 Main conclusions

It is not easy to say whether the improved varieties or the genebank accessions are most useful for diversification. Rather, it is important to encourage the use of improved varieties as well as the direct use of genebank accessions. Increased varietal choice allows coffee farmers in Costa Rica to diversify their farms more effectively than when they only have access to current commercial varieties. This wider varietal choice allows farmers to find those that fit their specific needs and farm conditions, motivating them to diversify both with new varieties and new crops.

According to farmers' preference and characterization data, commercial varieties dominated in standard market characteristics such as fruit weight. However, in all other farmer-preferred traits, CATIE and AVRDC varieties did just as well or better than commercial varieties. Not all farmers were searching for the varieties with the best commercial market characteristics. Therefore, taking into consideration farmer motives allows a more focused varietal selection.

Weighted farmer scores should be taken into consideration in future participatory evaluation projects. As this project shows, applying weighted values is very important since preferred varieties can change drastically based on the weights assigned to each farmer-preferred trait.

Significant interactions among variety, altitude and type of management illustrated by an analysis of the characterization and evaluation data showed that increased varietal choice enables farmers to choose varieties best suited to their environments and type of management. This again highlights the importance of allowing farmers to choose the varieties that do best on their farms. Using homogenous varietal options in heterogeneous environmental conditions is not the most effective way to diversify farms and will not motivate farmers to diversify with new crops.

New and improved vegetable varieties are often created using genes from traditional varieties that have specific characteristics, such as increased pest and disease resistance (Ebert 2014). In this study, we see that both improved AVRDC varieties and traditional CATIE accessions of tomato and sweet pepper demonstrated equal if not higher resistance to pests and diseases than the tested commercial varieties.

For a more efficient use of germoplasm material, farmers should be connected directly to genebanks. Genebanks should offer seeds and/or seedlings of a diverse selection of promising material directly to farmers or local greenhouses for on-farm use and distribution among local seed systems. Access to genebank material must be made easy and understandable to make this direct link between farmers and the genebank possible.

Apart from this direct link, nongovernmental and governmental organizations should also be connected to the diverse genetic resources of genebanks. This will allow them to offer a wider variety selection to farmers during capacity-building activities or other initiatives. Government subsidies would help encourage on-farm diversification. By offering subsidies to farmers who are 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.

As Van Bueren *et al. (2005)* demonstrated, this study highlights the importance of participatory research and evaluation with farmers when choosing varieties that are better adapted to specific enviornmental and management conditions. Coffee farmers in Turrialba enjoy participatory evaluation projects because it gives them the chance to learn more as well as discover new tomato and sweet pepper varieties that they consider not to be easily available.

More participatory evaluation projects should be undertaken in order to collect information on promising varieties for diversification. In order to effectively use the wide range of genetic material found in genebanks, further on-farm trials must be carried out that allow phenotypic information to be generated for specific varieties in different environments.

However, while participatory evaluation brings many benefits to farmers, it is a time-consuming and resource-intense process. Various improvements can be suggested for the improvement of participatory evaluation, such as an increase in the number of varieties tested and a decrease in the number of producers involved in the study. Also, the selection of producers to be involved in the participatory evaluation should be more selective, making sure that all farmers selected have a high level of commitment.

For the participatory evaluation process to be sustainable, local and on-farm seed systems must be improved. This will allow farmers to save and reproduce seeds of preferred varieties on the farm, so that they are not dependent on buying commercial seeds of commercially available varieties each year.

1.6 References

Almekinders, CJ ; Thiele, G y Danial, DL. 2007. Can cultivars from participatory plant breeding improve seed provision to small-scale farmers? Euphytica 1533:363-372.

Alvim, PdT. 1980. Aperspective appraisal of perennial crops in the Amazon Basin. Colombia, CIAT.

Baca, M ; Läderach, P ; Haggar, J ; Schroth, G y Ovalle, O. 2014. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. PloS one 92:e88463. Available at http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0088463#pone-0088463-g007

Bacon, C. 2005. Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua? World Development 333:497-511.

Bacon, C ; Mendez, E y Brown, M. 2005. Participatory action research and support for community development and conservation: examples from shade coffee landscapes in Nicaragua and El Salvador. Center for Agroecology & Sustainable Food Systems:

Bacon, CM ; Sundstrom, WA ; Flores Gómez, ME ; Ernesto Méndez, V ; Santos, R ; Goldoftas, B y Dougherty, I. 2014. Explaining the 'hungry farmer paradox': Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. Global Environmental Change 25:133-149.

Bioversity International. (2014, Cambridge. United Kingdom). 2014. International Conference on Enhanced genepool Utilization - Capturing wild relative and landrace diversity for crop improvement. Rome, Italy, 143 p. Consultado 27 Nov 2014.

Bioversity International. 2014. Strategic action plan to strengthen conservation and use of Mesoamerican plant genetic resources in adapting agriculture to climate change (SAPM) 2014-2024. Cali, Colombia, Bioversity International. Consulted 25 Oct 2014.

Bonham, C. 2011. Improving food security by linking G=genebanks to farmers through the direct release of targeted landace varieties.13. Consulted 7 Nov 2014.

Buck, M y Hamilton, C. 2011. The Nagoya Protocol on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization to the Convention on Biological Diversity. Review of European Community & International Environmental Law 201:47-61.

Caswell, M ; Méndez, VE y Bacon, CM. 2012. Food security and smallholder coffee production: current issues and future directions.

Caswell, M ; Méndez, VE ; Baca, M ; Läderach, P ; Liebig, T ; Castro-Tanzi, S y Fernández, M. 2014. Revisiting the "thin months"–A follow-up study on the livelihoods of Mesoamerican coffee farmers.

Ceccarelli, S y Grando, S. 2007. Decentralized-participatory plant breeding: an example of demand driven research. Euphytica 1553:349-360.

Ciancaleoni, S ; Raggi, L y Negri, V. 2014. Genetic outcomes from a farmer-assisted landrace selection programme to develop a synthetic variety of broccoli. Plant Genetic Resources:1-4.

Danial, D ; Parlevliet, J ; Almekinders, C y Thiele, G. 2007. Farmers' participation and breeding for durable disease resistance in the Andean region. Euphytica 1533:385-396.

Davis, AP ; Gole, TW ; Baena, S y Moat, J. 2012. The impact of climate change on indigenous arabica coffee (Coffea arabica): predicting future trends and identifying priorities. PloS one 711:e47981.

De Swart, EA ; Marcelis, LF y Voorrips, RE. 2006. Variation in relative growth rate and growth traits in wild and cultivated Capsicum accessions grown under different temperatures. Journal of Horticultural Science and Biotechnology 816:1029-1037.

Di Falco, S y Perrings, C. 2003. Crop genetic diversity, productivity and stability of agroecosystems. A theoretical and empirical investigation. Scottish Journal of Political Economy 502:207-216.

Eagles, H y Lothrop, J. 1994. Highland maize from Central Mexico—its origin, characteristics, and use in breeding programs. Crop Science 341:11-19.

Eakin, H ; Tucker, C y Castellanos, E. 2006. Responding to the coffee crisis: a pilot study of farmers' adaptations in Mexico, Guatemala and Honduras. The Geographical Journal 1722:156-171.

Ebert, AW. 2014. Potential of underutilized traditional vegetables and legume crops to contribute to food and nutritional security, income and more sustainable production systems. Sustainability 61:319-335.

Engels, J ; Ebert, A ; Thormann, I y De Vicente, M. 2006. Centres of crop diversity and/or origin, genetically modified crops and implications for plant genetic resources conservation. Genetic Resources and Crop Evolution 538:1675-1688.

FAO. 2009. International Treaty on Plant Genetic Resources for Food and Agriculture. Trad. Fao. Rome, Italy, 68 p. Consultado 30 Oct 2014.

Flores, M. 2002. Centroamérica: El impacto de la caída de los precios del café. United Nations Publications. Available at http://books.google.co.cr/books?hl=en&lr=&id=lxJ4gFQocEgC&oi=fnd&pg=PA10&dq=+Centroam%C3%A9rica:+El+Impacto+de+la+Ca%C3%ADda+de+los+Precios+del+Caf%C3%A9+en+el+2001&ots=WYy8jEC37Z&sig=2WxsJhWBNSkSopgDJ6VQwqWGKj0&redir_esc=y#v=onepage&q=Centroam%C3%A9rica%3A%20El%20Impacto%20de%20la%20Ca%C3%ADda%20de%20los%20Precios%20del%20Caf%C3%A9%20en%20el%202001&f=false

Friis-Hansen, E y Sthapit, B. 2000. Participatory approaches to the conservation and use of plant genetic resources. Bioversity International.

Halewood, M ; Deupmann, P ; Sthapit, B ; Vernoy, R y Ceccarelli, S. 2007. Participatory plant breeding to promote farmer's rights. Bioversity International.

Hammer, K y Diederichsen, A. 2009. Evolution, status and perspectives for landraces in Europe. European landraces on-farm conservation, management and use. Bioversity Technical Bulletin 15:23-44.

Hethcote, L. 10 Nov 2014. Preguntas claves con productores de cafe en San Juan Norte y Alto Varas, Cartago, Costa Rica Turrialba, Costa Rica, CATIE.

ICAFE. 2014. http://www.ICAFE.go.cr/.

Lin, BB. 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 613:183-193.

Mendez, VE ; Bacon, CM ; Olson, M ; Morris, KS y Shattuck, A. 2010. Agrobiodiversity and shade coffee smallholder livelihoods: A review and synthesis of ten years of research in Central America*. The Professional Geographer 623:357-376.

Mercer, KL y Perales, HR. 2010. Evolutionary response of landraces to climate change in centers of crop diversity. Evolutionary Applications 35-6:480-493.

Morris, KS ; Mendez, VE y Olson, MB. 2013. 'Los meses flacos': seasonal food insecurity in a Salvadoran organic coffee cooperative. The Journal of Peasant Studies 402:423-446.

Scheldeman, X ; Van Damme, P ; Urena Alvarez, J y Romero Motoche, J. 2001. Horticultural potential of Andean fruit crops exploring their centre of origin. *In*. p. 97-102.

Sthapit, B y Padulosi, S. 2012. On-farm conservation of neglected and underutilized crops in the face of climate change. In. p. 31.

Van Bueren, EL ; Van Soest, L ; De Groot, E ; Boukema, I y Osman, A. 2005. Broadening the genetic base of onion to develop better-adapted varieties for organic farming systems. Euphytica 1461-2:125-132.

Vasquez, N ; Solano, W. Reunion sobre los Recursos geneticos de plantas para la alimentacion y agricultura (2014, San Jose, Costa Rica). 2014. Eds. N Vasquez; W Solano.

Witcombe, J ; Joshi, A ; Joshi, K y Sthapit, B. 1996. Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. Experimental Agriculture 3204:445-460.

Witcombe, J ; Joshi, K ; Gyawali, S ; Musa, A ; Johansen, C ; Virk, D y Sthapit, B. 2005. Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding. Experimental Agriculture 413:299-320.

Witcombe, JR. 2003. Impacts of participatory varietal selection and participatory plant breeding on crop diversity. Conservation and Sustainable Use of Agricultural Biodiversity Strengthening Local Management of Agricultural DiversityII:322-330.

Zhu, Y ; Chen, H ; Fan, J ; Wang, Y ; Li, Y ; Chen, J ; Fan, J ; Yang, S ; Hu, L y Leung, H. 2000. Genetic diversity and disease control in rice. Nature 4066797:718-722.

Zonneveld, MV. Conversation with Maarten Von Zonneveld CATIE, Turrialba, Costa Rica.

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?

To be submitted to the journal, "Agronomy for Sustainable Development"

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).

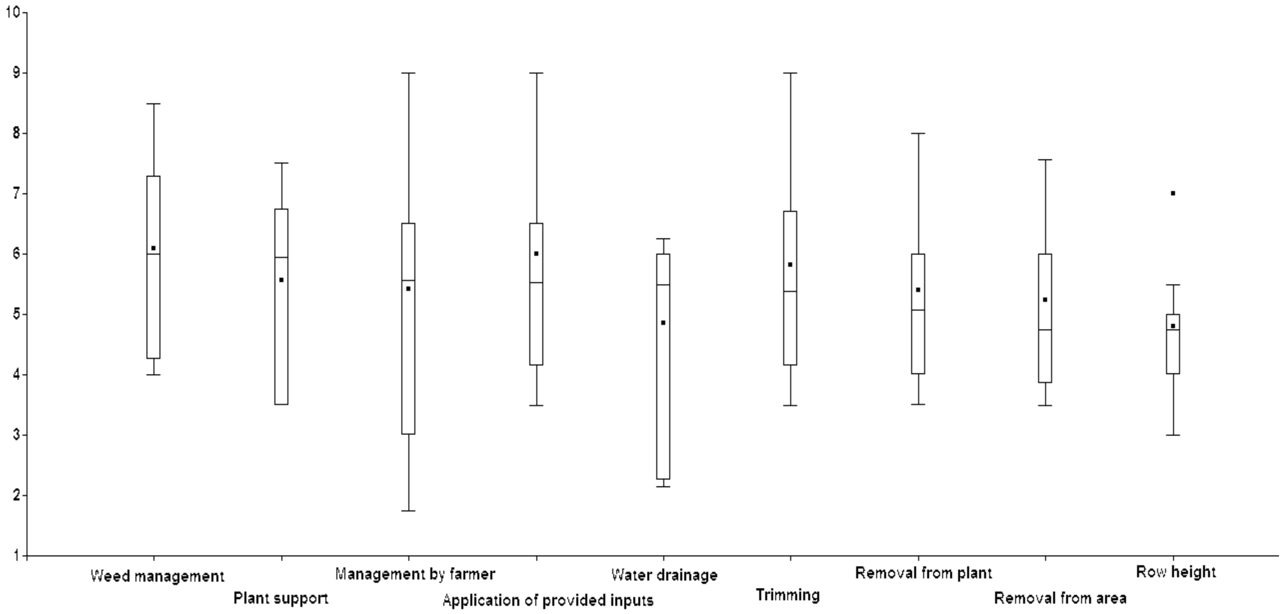


Figure 3. Bar graph of average farmer-management scores.

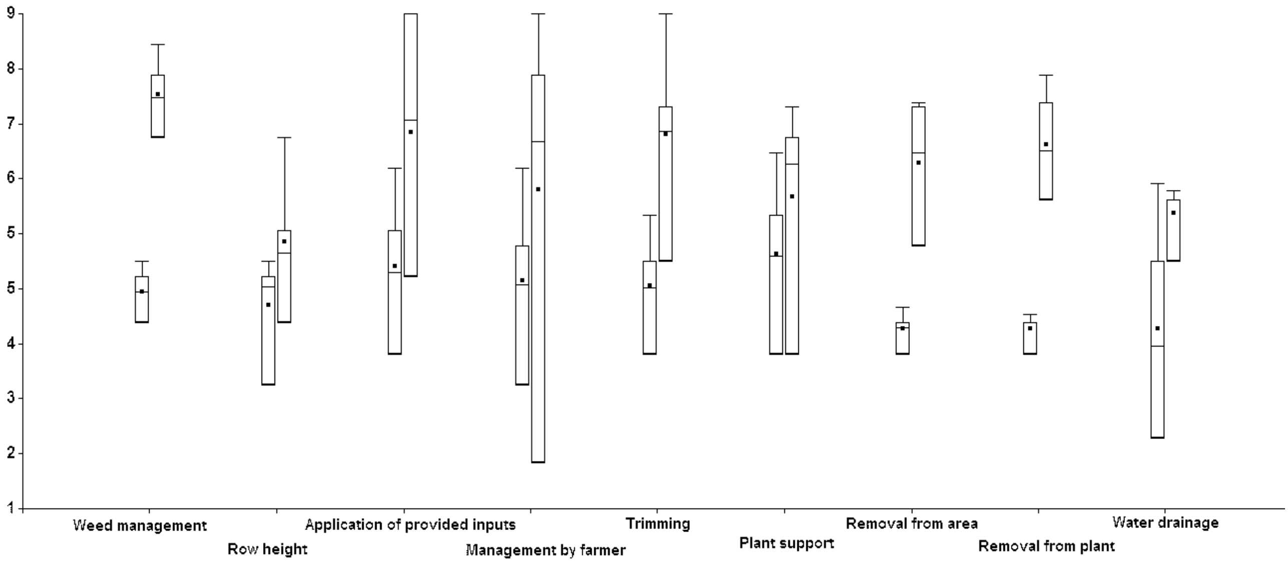


Figure 4. Bar graph of average farmer-management scores under both types of management

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.

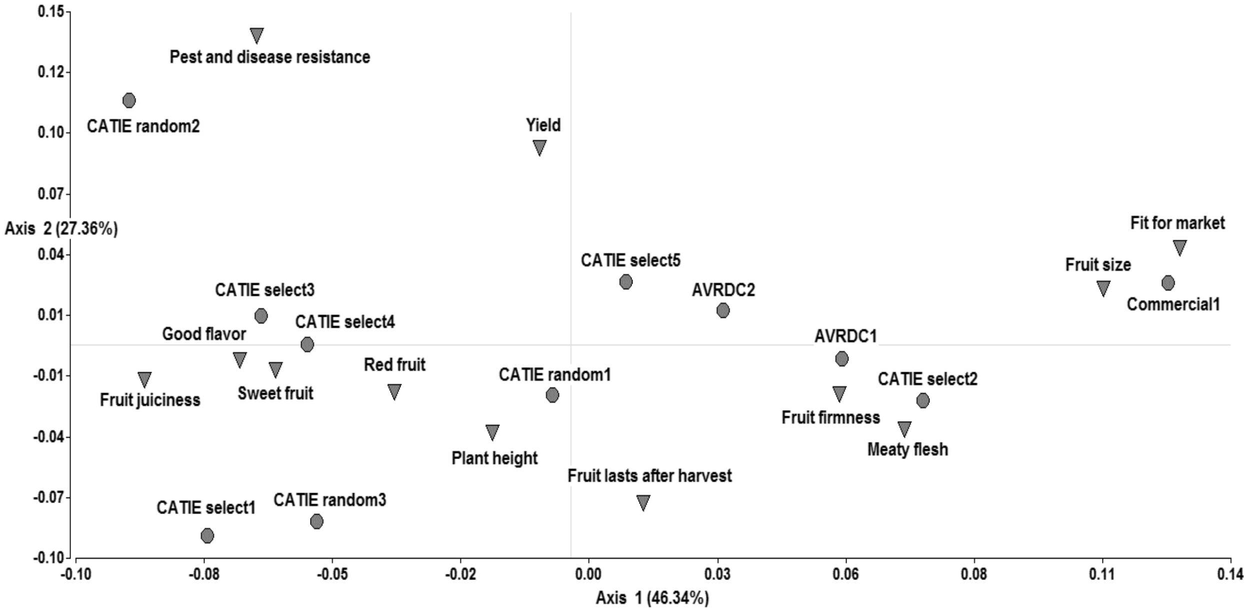


Figure 5. Correspondence analysis of tomato varieties and accessions and farmers' scores by farmer-preferred traits

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.

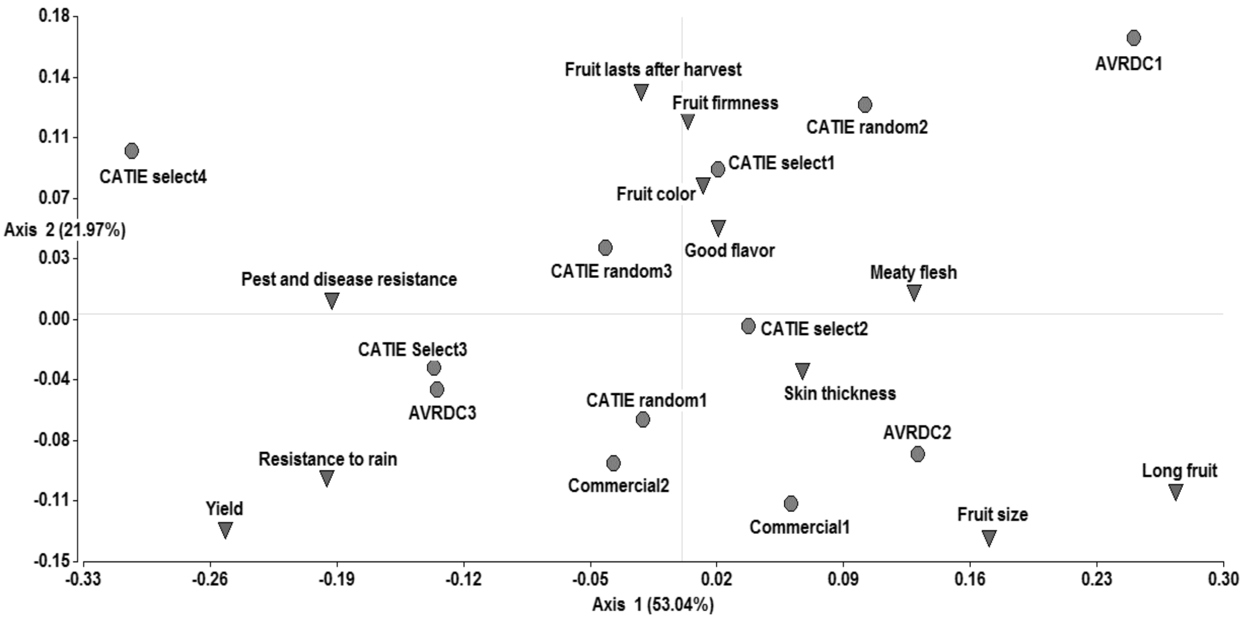


Figure 6. Correspondence analysis of sweet pepper varieties and accessions and farmers' scores by farmer-preferred traits

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).

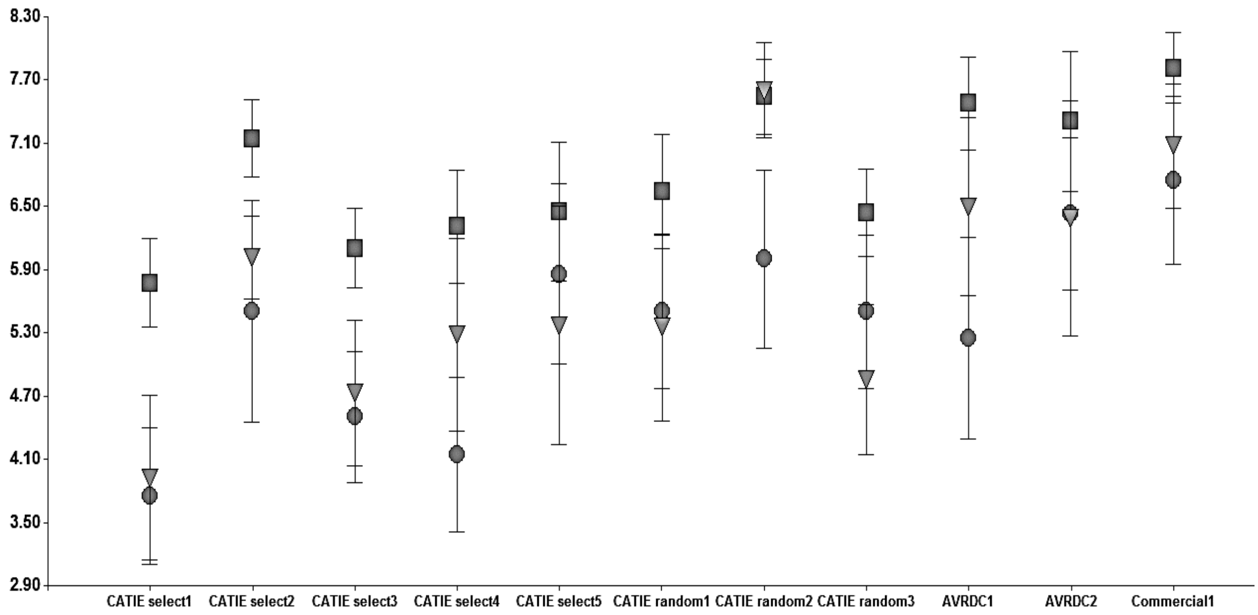


Figure 7. Dot plot of farmers' preferences for tomato varieties and accessions

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).

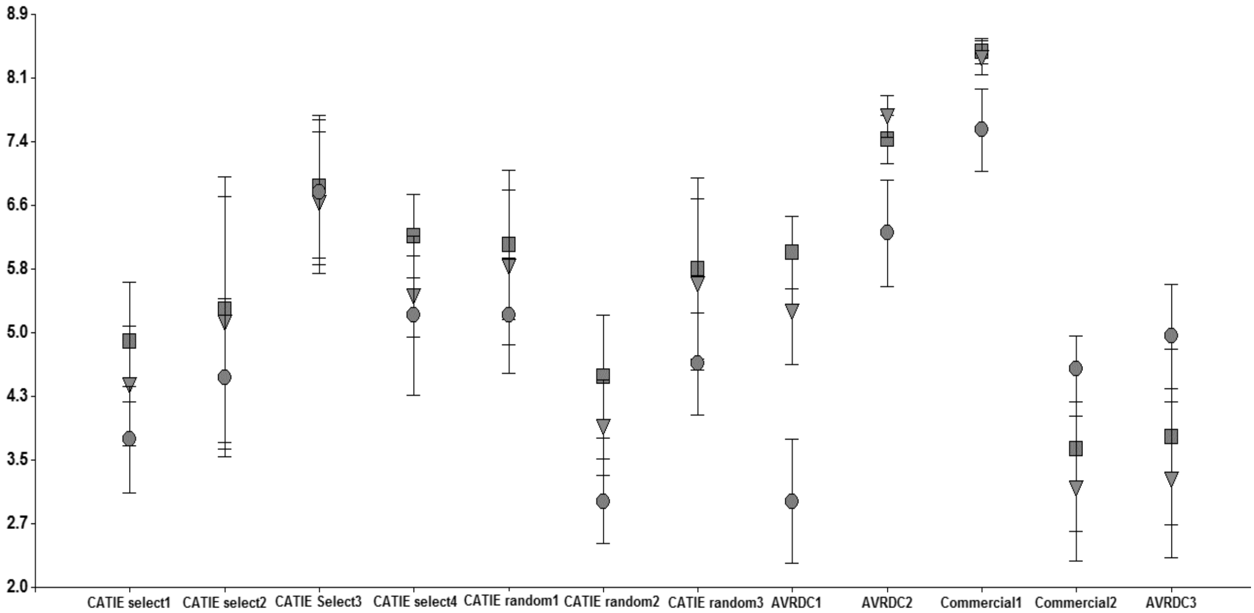


Figure 8. Dot plot of farmers' preferences for sweet pepper varieties and accessions

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).

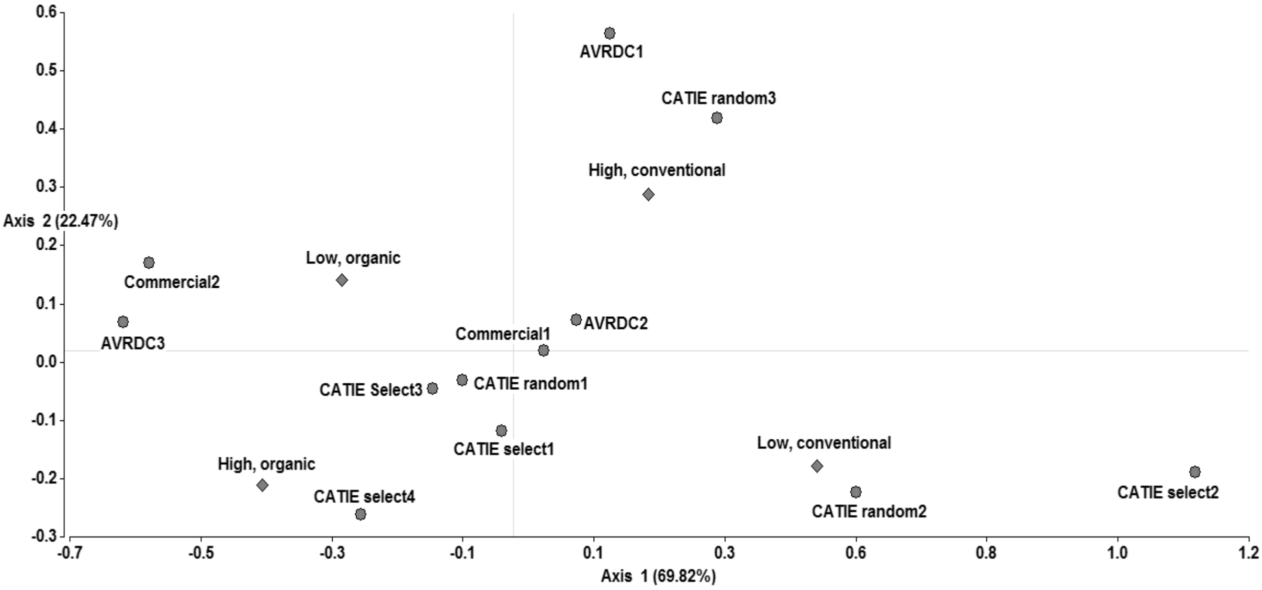


Figure 9. Correspondence analysis demonstrating farmer-preferred sweet pepper varieties and accessions at both altitudes and under both types of management

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	Susceptibility 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).

2.6 References

Almekinders, CJ ; Thiele, G y Danial, DL. 2007. Can cultivars from participatory plant breeding improve seed provision to small-scale farmers? Euphytica 1533:363-372.

Araya-Villalobos, R y Hernández-Fonseca, JC. 2006. Participative breeding of the local bean variety "Sacapobres" in Costa Rica. Agronomía Mesoamericana 173:347-355. Reimpreso de: Author affiliation: Estación experimental fabio baudrit moreno, Universidad de Costa Rica, Apartado postal 2645-3000, Heredia, Costa Rica. Author Email: avillalo@cariari.ucr.ac.cr

Atlin, G ; Cooper, M y Bjørnstad, Å. 2001. A comparison of formal and participatory breeding approaches using selection theory. Euphytica 1223:463-475.

Baca, M ; Läderach, P ; Haggar, J ; Schroth, G y Ovalle, O. 2014. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. PloS one 92:e88463. Available at http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0088463#pone-0088463-g007

Bacon, C. 2005. Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in northern Nicaragua? World Development 333:497-511.

Bacon, C ; Mendez, E y Brown, M. 2005. Participatory action research and support for community development and conservation: examples from shade coffee landscapes in Nicaragua and El Salvador. Center for Agroecology & Sustainable Food Systems.

Bacon, CM ; Sundstrom, WA ; Flores Gómez, ME ; Ernesto Méndez, V ; Santos, R ; Goldoftas, B y Dougherty, I. 2014. Explaining the ‘hungry farmer paradox’: Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. Global Environmental Change 25:133-149.

Bertero, H ; De la Vega, A ; Correa, G ; Jacobsen, S y Mujica, A. 2004. Genotype and genotype-by-environment interaction effects for grain yield and grain size of quinoa (Chenopodium quinoa Willd.) as revealed by pattern analysis of international multi-environment trials. Field Crops Research 892:299-318.

Bioversity International. (2014, Cambridge. United Kingdom). 2014. International conference on enhanced genepool utilization - Capturing wild relative and landrace diversity for crop improvement. Rome, Italy, 143 p. Consulted 27 Nov 2014.

Bioversity International. 2014. Strategic action plan to strengthen conservation and use of Mesoamerican plant genetic resources in adapting agriculture to climate change (SAPM) 2014-2024. Cali, Colombia, Bioversity International. Consultado 25 Oct 2014.

Carvalho, MAAPd ; Bebeli, PJ ; Bettencourt, E ; Costa, G ; Dias, S ; Santos, TMMd y Slaski, JJ. 2013. Cereal landraces genetic resources in worldwide GeneBanks. A review. Agronomy for Sustainable Development 331:177-203. Reimpreso de: Author Affiliation: ISOPlexis Germplasm Bank, University of Madeira, Campus da Penteada, 9000-390, Funchal, Portugal. Author Email: jan.slaski@albertainnovates.ca

Caswell, M ; Méndez, VE y Bacon, CM. 2012. Food security and smallholder coffee production: current issues and future directions.

Caswell, M ; Méndez, VE ; Baca, M ; Läderach, P ; Liebig, T ; Castro-Tanzi, S y Fernández, M. 2014. Revisiting the “thin months”–a follow-up study on the livelihoods of Mesoamerican coffee farmers.

Ceccarelli, S y Grando, S. 2007. Decentralized-participatory plant breeding: an example of demand driven research. Euphytica 1553:349-360.

Ciancaleoni, S ; Raggi, L y Negri, V. 2014. Genetic outcomes from a farmer-assisted landrace selection programme to develop a synthetic variety of broccoli. Plant Genetic Resources:1-4.

Danial, D ; Parlevliet, J ; Almekinders, C y Thiele, G. 2007. Farmers’ participation and breeding for durable disease resistance in the Andean region. Euphytica 1533:385-396.

De la Peña, R y Hughes, J. 2007. Improving vegetable productivity in a variable and changing climate. Journal of SAT Agricultural Research 41:1-22.

De Swart, EA ; Marcelis, LF y Voorrips, RE. 2006. Variation in relative growth rate and growth traits in wild and cultivated Capsicum accessions grown under different temperatures. Journal of Horticultural Science and Biotechnology 816:1029-1037.

Ebert, AW. 2014. Potential of underutilized traditional vegetables and legume crops to contribute to food and nutritional security, income and more sustainable production systems. Sustainability 61:319-335.

FAO. 2009. International treaty on plant genetic resources for food and agriculture. Trad. Fao. Rome, Italy, 68 p. Consulted 30 Oct 2014.

Friis-Hansen, E y Sthapit, B. 2000. Participatory approaches to the conservation and use of plant genetic resources. Bioversity International.

Gautam, U ; Negi, R ; Singh, R ; Kaushik, S y Singh, A. 2013. Participatory evaluation of tomato varieties for commercial cultivation during rainy season under Kaymore

Plateau and Satpura Hills–Agro-climatic zone of Madhya Pradesh. Journal of Agricultural Science 54:p238.

Halewood, M ; Deupmann, P ; Sthapit, B ; Vernoy, R y Ceccarelli, S. 2007. Participatory plant breeding to promote farmer's rights. Bioversity International.

ICAFE. 2014. http://www.ICAFE.go.cr/.

IPGRI ; AVRDC y CATIE. 1995. Descriptors for Capsicum (Capsicum spp.). Rome, Italy, Consultado 25 Nov 2014.

IPGRI. 1996. Descriptors for tomato (Lycopersicon spp.). Rome, Italy, Consulted 25 Oct 2014.

Jacobsen, S-E ; Sørensen, M ; Pedersen, SM y Weiner, J. 2015. Using our agrobiodiversity: plant-based solutions to feed the world. Agronomy for Sustainable Development:1-19.

Jäger, M ; van Zonneveld, M ; Ramirez, M y Amaya, K. Linking genebanks and farmers to urban markets-native chili peppers in Peru and Bolivia.

Joshi, A y Witcombe, JR. 1996. Farmer participatory crop improvement. II. Participatory varietal selection, a case study in India. Experimental Agriculture 3204:461-477.

Kirschenmann, FL. 2007. Potential for a new generation of biodiversity in agroecosystems of the future. Agronomy Journal 992:373-376.

Lin, BB. 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 613:183-193.

Mercer, KL y Perales, HR. 2010. Evolutionary response of landraces to climate change in centers of crop diversity. Evolutionary Applications 35-6:480-493.

Mittra, S ; van Etten, J y Franco, T. 2013. Collecting weather data in the field with high spatial and temporal resolution using iButtons.

Morris, KS ; Mendez, VE y Olson, MB. 2013. 'Los meses flacos': seasonal food insecurity in a Salvadoran organic coffee cooperative. The Journal of Peasant Studies 402:423-446.

Mulatu, E y Zelleke, H. 2002. Farmers' highland maize (Zea mays L.) selection criteria: Implication for maize breeding for the Hararghe highlands of eastern Ethiopia. Euphytica 1271:11-30.

Oluoch, M ; Silué, D ; Nono-Womdim, R ; Hanson, P ; Black, L ; Wang, T ; Ojiewo, C y Swai, I. 2009. Participatory cultivar evaluation, selection, and release of Late Blight resistant romato cultivars in Tanzania. *In*. p. 199-206.

Quesada-Ocampo, L y Hausbeck, M. 2010. Resistance in tomato and wild relatives to crown and root rot caused by Phytophthora capsici. Phytopathology 1006:619-627.

Scheldeman, X ; Van Damme, P ; Urena Alvarez, J y Romero Motoche, J. 2001. Horticultural potential of Andean fruit crops exploring their centre of origin. *In*. p. 97-102.

Thomas, M ; Verzelen, N ; Barbillon, P ; Coomes, OT ; Caillon, S ; McKey, D ; Elias, M ; Garine, E ; Raimond, C y Dounias, E. 2015. A network-based method to detect patterns of local crop biodiversity: validation at the species and infra-species levels. Advances in Ecological Research.

Tshewang, U ; Hardon, JJ y Tamang, A. 2003. Integrating in situ and ex situ conservation with on-farm use. Conservation and Sustainable use of Agricultural Biodiversity Strengthening Local Management of Agricultural DiversityII:368-375.

Van Bueren, EL ; Van Soest, L ; De Groot, E ; Boukema, I y Osman, A. 2005. Broadening the genetic base of onion to develop better-adapted varieties for organic farming systems. Euphytica 1461-2:125-132.

Witcombe, J ; Joshi, A ; Joshi, K y Sthapit, B. 1996. Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. Experimental Agriculture 3204:445-460.

Witcombe, J ; Joshi, K ; Gyawali, S ; Musa, A ; Johansen, C ; Virk, D y Sthapit, B. 2005. Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding. Experimental Agriculture 413:299-320.

Witcombe, JR. 2003. Impacts of participatory varietal selection and participatory plant breeding on crop diversity. Conservation and Sustainable Use of Agricultural Biodiversity: Strengthening Local Management of Agricultural DiversityII:322-330.

Wood, D y Lenne, JM. 1997. The conservation of agrobiodiversity on-farm: questioning the emerging paradigm. Biodiversity & Conservation 61:109-129.

Zhu, Y ; Chen, H ; Fan, J ; Wang, Y ; Li, Y ; Chen, J ; Fan, J ; Yang, S ; Hu, L y Leung, H. 2000. Genetic diversity and disease control in rice. Nature 4066797:718-722.

Zonneveld. 25 August 2014. Conversation with Maarten Von Zonneveld CATIE, Turrialba, Costa Rica.

3. Chapter III. Article II: Improving access to vegetable seeds for diverse and resilient farms: Lessons learned from coffee farmers in Turrialba, Costa Rica

Submitted to "Farming Matters" journal

A group of coffee farmers in Turrialba, Costa Rica, is successfully exploring diversification options with horticultural food crops. This is being done in collaboration with two vegetable genebanks that allow farmers to use varieties freely under the MultiLateral System of FAO´s International Treaty on Plant Genetic Resources for Food and Agriculture.

Experiments with tomato and sweet pepper varieties were successful and show promise for helping farmers gain access to genetic resources of horticultural crops. The resulting diversity could be the basis for diversified farming systems that are more resilient in progressive climate change and price volatility, while providing nutritious food crops at the same time. This case study therefore calls for the inclusion of more horticultural crops in the Annex 1 list of species covered by the Multilateral System (MLS, Annex 1, p. 46–47), such as tomato and sweet pepper.

3.1 Why mix coffee production with tomato and sweet pepper crops?

In Turrialba, Costa Rica, climate change and low coffee prices motivated small-scale coffee farmers to spread risk and diversify their farms by integrating new crops. Eight small-scale coffee farmers in Turrialba chose to participate in an experiment with tomato and sweet pepper led by CATIE. These crops were chosen for the experiment for the following reasons:

1) These horticultural crops are of great interest to farmers in this region as alternative cash crops that are complementary with coffee, as well as for domestic consumption

2) The genebanks of the Tropical Agricultural Research and Higher Education Center CATIE and The World Vegetable Center (AVRDC) maintain highly diverse collections of these two crops, providing the necessary variety for selection of interesting materials. They are also openly accessible under the Multilateral System (MLS) established by FAO´s International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

The experiment's premise is that diversified farming systems are often ecologically and economically more resilient than those with less components. Diversified systems provide farmers with a range of resources, including stabilization of income and production and diverse food for consumption. This diversity has been shown to result in systems becoming more resilient to climate change and price volatility.

However, farmers often do not have access to appropriate seed material to diversify their systems with food and/or cash crops compatible with their interests. In this project, we explore how access to diverse genetic material can improve a farmer's ability to effectively diversify his or her farm in a way that makes it resilient and sustainable.

3.2 How did farmers conduct the experiment?

Eight farmers, four organic and four conventional, were invited to participate in the study based on their interest in diversification and willingness to participate. The farmers evaluated three types of tomato and sweet pepper seeds. These included 1) popular commercial varieties, 2) traditional varieties from CATIE's genebank in Costa Rica that were selected according to farmers' preferences indicated in initial interviews and 3) new varieties that were developed by breeders from AVRDC in Taiwan to respond to specific biotic and abiotic conditions in Central America.

Seeds from CATIE's genebank were ordered using the Standard Material Transfer Agreement (SMTA) developed by ITPGRFA. Seeds of the AVRDC varieties were obtained by CATIE after signing a Material Transfer Agreement (MTA) to test them in Central America. In addition, the most common commercial varieties of tomato and sweet pepper were ordered from a local greenhouse.

After the seedlings were transplanted on each farm, plastic bands were installed as protective roofs above each variety. Conventional and organic seedlings were given to each producer, along with a management guide that was used to ensure the same management approaches were used on all farms.

Each farm was visited once a week from the time the transplant began, April 2015, until the end of the field experiments, November 2015. During the visits, the following data were taken: 1) morphological and evaluation data of each variety; 2) site characterization of each farm; 3) management evaluation of each producer; 4) climate data; 5) yield data; 6) participatory evaluations with the producers and 6) individual interviews with the producers about their preferences.

3.3 Farmers' preferences

Many factors affected variety preferences of each farmer, including the type of management used on the farm, local market factors and local biotic factors. Although many farmers appreciated the commercial varieties because of their pest and disease resistance and high yields, several CATIE accessions as well as a few AVRDC varieties were ranked as equally or even more preferred.

Most producers involved in this project expressed satisfaction with the new varieties brought to their farms, which they had never seen. Rosa Hernández Céspedes, a coffee farmer who has been trying to diversify her 7-hectare farm for the past eight years, is very excited.

"These new varieties also give us something new to sell," she said." The local people want new kinds of vegetables, new options, but I never knew where to find the seeds. So I have started saving the seeds from the new varieties and I can now sow my own seedlings and produce these great vegetables again."

What started out as strictly a coffee plantation had already been converted by Rosa into a diverse, organic farm that includes a vegetable greenhouse, a restaurant and a nursery of tree species. Yet, before her involvement in this project, Rosa had little success in diversifying with vegetables, as expressed in the following statement:

"I always planted the same commercial varieties of vegetables, including commercial varieties of tomato and sweet pepper. But with this project, I have discovered many traditional varieties of great quality, some of which are more resistant to the increase in rain we have had this year. It's great to have all of these new options on the farm."

For farmers like Rosa who are searching for diverse products with unique characteristics, the traditional CATIE accessions were of most interest. Many of the traditional varieties tested in the study showed characteristics that were appealing to these farmers, such as high resistance to pests and diseases as well as fruit forms that were uncommon but often preferred. The commercial varieties were often most preferred by producers selling strictly to the conventional market.

3.4 What lessons can be drawn from this study?

This study shows the importance of facilitating farmers' and breeders´ access to the genetic resources of horticultural crops and the key role that accessible collections could fill, such as those of CATIE and AVRDC. Tomato and sweet peppers, as well as other important vegetable crops such as cucurbits, are not yet part of the list of crops covered directly by the Multilateral System. This means that having access to improved varieties to these crops is very hard for small-scale family farmers because of the bureaucracy, cost and intellectual property rights involved.

Although the resources contained within genebank collections are important, without proper access to particular information by farmers, breeders and agronomists, the material cannot be used efficiently. In this study, for example, morphological data of genebank accessions was used to select the varieties according to farmers' preferences and their on-farm potential was evaluated under different conditions. It is important that such morphological characterization and evaluation data is made accessible by genebanks to enhance its use by different actors.

On the basis of this study, we propose six measures to improve access to growers and breeders once the crops are included in the MLS:

1. A clear documentation system with relevant information on agronomic and other commercial properties of the crops covered by the MLS collection is made available in accessible language and media
2. An online system to directly request seeds, which also includes contact information for farmers in case of questions
3. Active assistance to farmers in negotiating an SMTA
4. Establishment of straightforward payment systems that cover the costs for regeneration of the material by the genebank, which should remain economically accessible to farmers and other breeders
5. Distribution of hardcopy catalogues that include the most promising materials and contact information for farmers and relevant organizations
6. Increase in the number of on-farm participatory varietal-validation research projects with farmers

When farmers have better access to information and seed material that is currently available in genebanks, they can broaden the genetic base of their crops. Our research shows that this is of interest to individual farmers and organizations who seek to diversify their farms in response to climatic or economic shocks and to strengthen their management of crop varieties by developing participatory evaluation and breeding programs.

3.5 Farmer-based experimentation

Farmers like Rosa are motivated to seek out new varieties and new markets to enhance their adaptive capacity. However, many producers have lost essential knowledge about ecosystem resilience and the way that diverse, traditional seed systems contribute to this resilience. Therefore, knowledge sharing must also be enhanced in addition to improved access to genebank material under multilateral seed systems if the material is going to be used effectively.

However, bringing this genetic material to farms cannot depend solely on outside intermediaries. Rather, we have seen that knowledge sharing works best when innovative smallholder farmers like Rosa encourage other producers to seek out new material and multiply and breed diverse varieties. Such horizontal learning and farmer-based experimentation should be at the center of knowledge-sharing processes, in which other parties (scientists, NGOs) can play a supportive role. This will contribute to the effective use of genetic resources for more resilient and sustainable farming communities.

4. Appendix

Appendix 1. Fertilization guide for organic and conventional farmers

Guía de Fertilización Orgánica

Los elementos más importantes en la fertilización del tomate y chile son el nitrógeno, fósforo, potasio, calcio, magnesio, boro y zinc.

Esquema General de fertilización

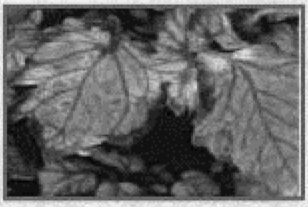
Epoca	Nutriente	Finalidad
Siembra	nitrogeno, fosforo, potasio	Enraizar
Antes de floración hasta cuajada (30-80 días después de transplante)	Magnesio	Participa de manera directa en el proceso de la fotosíntesis, balanceando eficientemente las relaciones de bases y por ende una mejor síntesis de proteínas.
floración al cuajado (50-70 días después de transplante)	Nitrato de Potasio	Interviene en la fotosíntesis, síntesis de clorofila; como activador de las enzimas e interviene en el balance hídrico de la planta.
floración al cuajado (50-70 días después de transplante)	Nitrato de Calcio	Participa en la formación y el fortalecimiento de las paredes y membranas celulares.
floración al cuajado (50-70 días después de transplante)	Boro	Mejora la absorción y el transporte de azúcares.
floración al cuajado (50-70 días después de transplante)	Zinc	Participa como activador enzimático y desempeña un importante papel en la síntesis de las proteínas.
cuajado a cosecha (60-120 días después del transplante)	Nitrato de Calcio	Participa en la formación y el fortalecimiento de las paredes y membranas celulares.
cuajado a cosecha (60-120 días después del transplante)	Nitrato de Potasio	Interviene en la fotosíntesis, síntesis de clorofila; como activador de las enzimas e interviene en el balance hídrico de la planta.

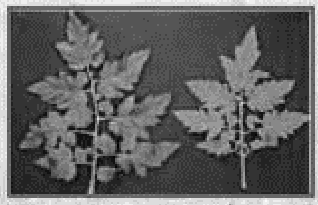
Plan específico de fertilización orgánica para este proyecto

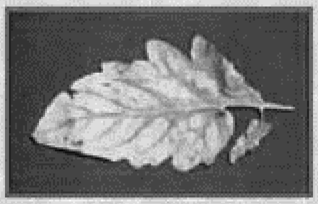
Epoca	fecha	Producto Orgánico
Siembra		Roca fosforica y gallinaza
5-7 dais despues		Sulfato de Potasio y Sulfato de Magnesio
Durante todo el ciclo de vida donde es necesario, especialmente antes de floración		Calcio
Durante todo el ciclo de vida donde es necesario, especialmente antes de floración		Boro
Durante todo el ciclo de vida donde es necesario, especialmente antes de floración		Zinc
Durante todo el ciclo de vida		Biofertilizantes y bioestimulantes completos

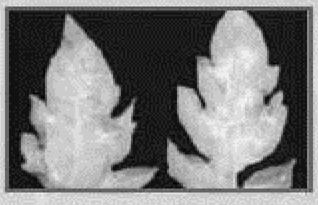
Identificación de Deficiencias en tomate

NUTRIENTE	SÍNTOMA DE DEFICIENCIA
Nitrógeno	Retraso en crecimiento vegetativo, coloración verde pálido en hojas inferiores con posterior amarillamiento, quema de hojas y defoliación. Frutas pequeñas, de bajo peso, maduración precoz y desuniforme.
Fósforo	Hojas viejas de color verde oscuro o azulado, con aparición posterior de manchas bronceadas o púrpuras Plantas pequeñas, con retraso en floración, caída de flores y frutos, maduración tardía de frutos.
Potasio	Acortamiento de entrenudos del tallo, hojas viejas con amarillamiento en bordes y puntas, posteriormente aparecen manchas necróticas de color marrón pálido en bordes y puntas de hojas, defoliación, frutos pequeños, con coloración externa desuniforme.
Calcio	Las hojas nuevas presentan márgenes necróticos, en plantas jóvenes las hojas se doblan hacia arriba formando una copa. El crecimiento radical se reduce y ocurre muerte de puntas de raíces. En frutos ocurre pudrición basal, deformación y maduración precoz.
Magnesio	Amarillamiento intervenal en hojas viejas, que puede extenderse al resto de las hojas, con necrosis posterior de área amarillentas.
Azufre	Amarillamiento de hojas iniciando por las más recientes.
Hierro	Clorosis intervenal de hojas nuevas, posteriormente las hojas adquieren un color casi blancuzco, reduciendo el crecimiento de nuevos brotes.
Cobre	Enrrollamiento hacia fuera de hojas nuevas, quema o necrosis de puntas de hojas nuevas rodeado de halo amarillento, muerte descendente de brotes nuevos.
Zinc	Amarillamiento intervenal de hojas nuevas, con necrosis posterior de zonas amarillentas.
Manganeso	Amarillamiento intervenal de hojas nuevas, siendo más marcado en las puntas de las hojas.
Boro	Puntas de hojas nuevas se tornan amarillentas y se doblan, posteriormente ocurre quema de zonas amarillentas, reducción del crecimiento, y en casos severos hay muerte del meristemo.


DEFICIENCIA DE MAGNESIO

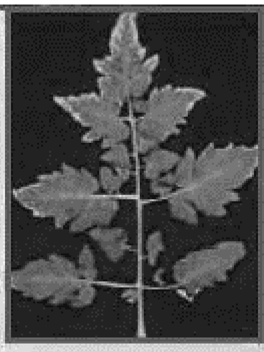

DEFICIENCIA DE NITRÓGENO


DEFICIENCIA DE MANGANESO


DEFICIENCIA DE FÓSFORO


DEFICIENCIA DE BORO


DEFICIENCIA DE ZINC

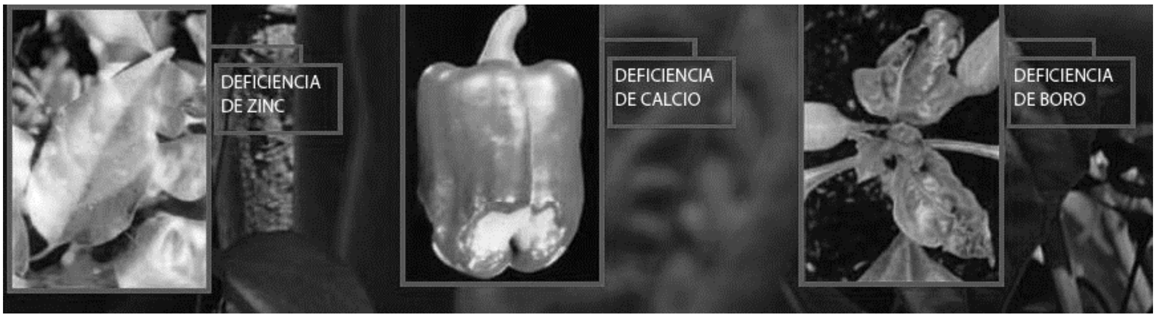

DEFICIENCIA DE POTASIO

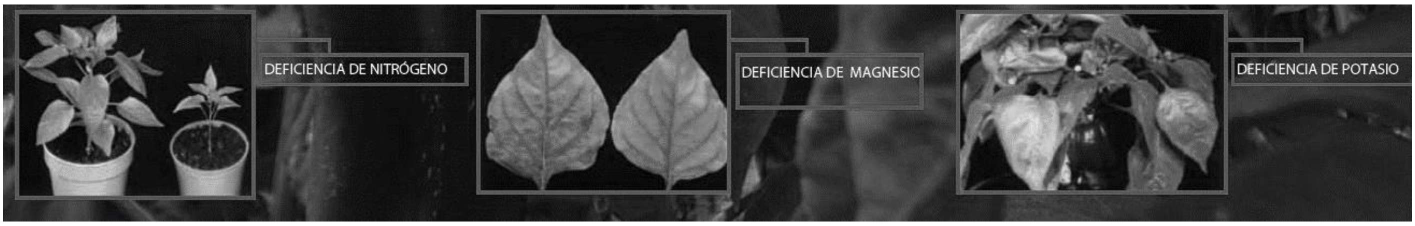

DEFICIENCIA DE CALCIO

Identificación de Deficiencias en chile

Síntomas de deficiencias nutricionales en chile

NUTRIENTE	SÍNTOMA DE DEFICIENCIA
Nitrógeno	Amarillamiento o clorosis general de hojas viejas, retraso en el crecimiento, reducción de floración, del peso y tamaño de frutas.
Fósforo	Plantas pequeñas, de escaso crecimiento radical, hojas viejas de color verde oscuro al inicio, luego aparecen manchas amarillentas, se reduce el número de flores y el cuaje.
Potasio	Amarillamiento en bordes y puntas de hojas más viejas, defoliación, frutos pequeños, con coloración externa desuniforme
Calcio	Amarillamiento de puntas de hojas nuevas, deformación y corrugamiento de hojas nuevas, disminución de crecimiento. En frutos se presenta pudrición basal y deformación.
Magnesio	Clorosis intervenal en hojas más viejas, con posterior quema de zonas amarillentas, reducción del crecimiento, en casos severos ocurre también defoliación
Azufre	Clorosis general del follaje, reducción del crecimiento.
Hierro	Amarillamiento general de hojas nuevas, hojas pequeñas
Cobre	Deformación y amarillamiento de hojas nuevas, iniciando en puntas de hojas.
Zinc	Clorosis intervenal de hojas nuevas, con aparición de manchas necróticas.
Manganeso	Coloración verde pálida en hojas nuevas con tendencia a amarillearse, manchas necróticas pequeñas en hojas nuevas.
Boro	Puntas de hojas nuevas se tornan amarillentas. Deformación y corrugamiento de hojas nuevas, muerte de puntas en crecimiento.





Guía de Fertilización Convencional

Los elementos más importantes en la fertilización del tomate y chile son el nitrógeno, fósforo, potasio, calcio, magnesio, boro y zinc.

Esquema General de fertilización

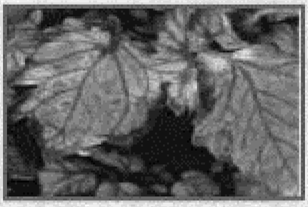
Epoca	Nutriente	Finalidad
Siembra	nitrogeno, fosforo, potasio	Enraizar
Antes de floración hasta cuajada (30-80 días después de transplante)	Magnesio	Participa de manera directa en el proceso de la fotosíntesis, balanceando eficientemente las relaciones de bases y por ende una mejor síntesis de proteínas.
floración al cuajado (50-70 días después de transplante)	Nitrato de Potasio	Interviene en la fotosíntesis, síntesis de clorofila; como activador de las enzimas e interviene en el balance hídrico de la planta.
floración al cuajado (50-70 días después de transplante)	Nitrato de Calcio	Participa en la formación y el fortalecimiento de las paredes y membranas celulares.
floración al cuajado (50-70 días después de transplante)	Boro	Mejora la absorción y el transporte de azúcares.
floración al cuajado (50-70 días después de transplante)	Zinc	Participa como activador enzimático y desempeña un importante papel en la síntesis de las proteínas.
cuajado a cosecha (60-120 días después del transplante)	Nitrato de Calcio	Participa en la formación y el fortalecimiento de las paredes y membranas celulares.
cuajado a cosecha (60-120 días después del transplante)	Nitrato de Potasio	Interviene en la fotosíntesis, síntesis de clorofila; como activador de las enzimas e interviene en el balance hídrico de la planta.

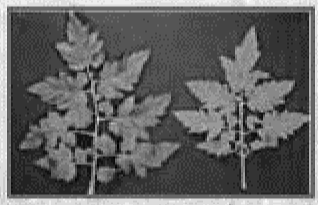
Plan específico de fertilización convencional para este proyecto

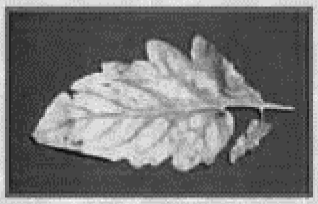
Época	Fecha	Producto Convencional
Siembra		10-30-10
15-22 días después del transplante		18-5-15
10 días después		Formula Multimineral y magnesio si es necesario
15 días después		Mezcla Física (Hidrocomplex) y magnesio si es necesario
15 días después		Kmag y magnesio si es necesario
Floración a cosecha		Rotación de Fertilizantes 18-5-15, Formula Multimineral Hidrocomplex y Kmag
Floración a cuajado		Nitrato de Potasio, Nitrato de Calcio, Boro, Zinc, Magnesio

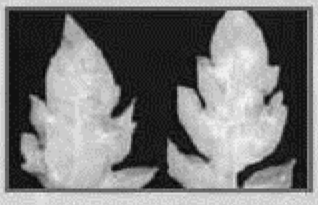
Identificación de Deficiencias en tomate

NUTRIENTE	SÍNTOMA DE DEFICIENCIA
Nitrógeno	Retraso en crecimiento vegetativo, coloración verde pálido en hojas inferiores con posterior amarillamiento, quema de hojas y defoliación. Frutas pequeñas, de bajo peso, maduración precoz y desuniforme.
Fósforo	Hojas viejas de color verde oscuro o azulado, con aparición posterior de manchas bronceadas o púrpuras Plantas pequeñas, con retraso en floración, caída de flores y frutos, maduración tardía de frutos.
Potasio	Acortamiento de entrenudos del tallo, hojas viejas con amarillamiento en bordes y puntas, posteriormente aparecen manchas necróticas de color marrón pálido en bordes y puntas de hojas, defoliación, frutos pequeños, con coloración externa desuniforme.
Calcio	Las hojas nuevas presentan márgenes necróticos, en plantas jóvenes las hojas se doblan hacia arriba formando una copa. El crecimiento radical se reduce y ocurre muerte de puntas de raíces. En frutos ocurre pudrición basal, deformación y maduración precoz.
Magnesio	Amarillamiento intervenal en hojas viejas, que puede extenderse al resto de las hojas, con necrosis posterior de área amarillentas.
Azufre	Amarillamiento de hojas iniciando por las más recientes.
Hierro	Clorosis intervenal de hojas nuevas, posteriormente las hojas adquieren un color casi blancuzco, reduciendo el crecimiento de nuevos brotes.
Cobre	Enrrollamiento hacia fuera de hojas nuevas, quema o necrosis de puntas de hojas nuevas rodeado de halo amarillento, muerte descendente de brotes nuevos.
Zinc	Amarillamiento intervenal de hojas nuevas, con necrosis posterior de zonas amarillentas.
Manganeso	Amarillamiento intervenal de hojas nuevas, siendo más marcado en las puntas de las hojas.
Boro	Puntas de hojas nuevas se tornan amarillentas y se doblan, posteriormente ocurre quema de zonas amarillentas, reducción del crecimiento, y en casos severos hay muerte del meristemo.


DEFICIENCIA DE MAGNESIO

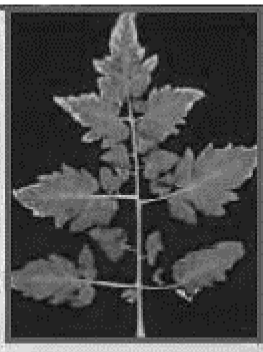

DEFICIENCIA DE NITRÓGENO


DEFICIENCIA DE MANGANESO


DEFICIENCIA DE FÓSFORO


DEFICIENCIA DE BORO


DEFICIENCIA DE ZINC

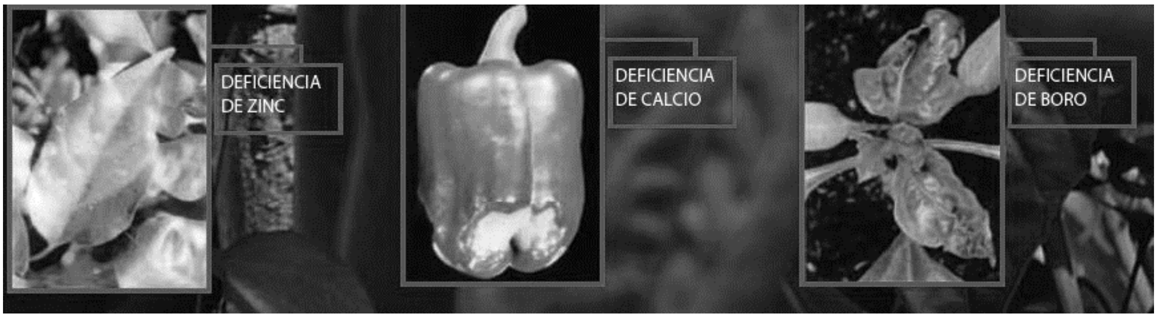

DEFICIENCIA DE POTASIO

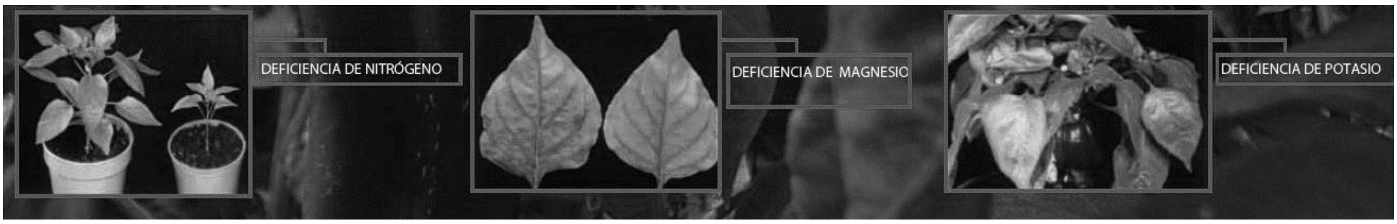

DEFICIENCIA DE CALCIO

Identificación de Deficiencias en chile

Síntomas de deficiencias nutricionales en chile

NUTRIENTE	SÍNTOMA DE DEFICIENCIA
Nitrógeno	Amarillamiento o clorosis general de hojas viejas, retraso en el crecimiento, reducción de floración, del peso y tamaño de frutas.
Fósforo	Plantas pequeñas, de escaso crecimiento radical, hojas viejas de color verde oscuro al inicio, luego aparecen manchas amarillentas, se reduce el número de flores y el cuaje.
Potasio	Amarillamiento en bordes y puntas de hojas más viejas, defoliación, frutos pequeños, con coloración externa desuniforme
Calcio	Amarillamiento de puntas de hojas nuevas, deformación y corrugamiento de hojas nuevas, disminución de crecimiento. En frutos se presenta pudrición basal y deformación.
Magnesio	Clorosis intervenal en hojas más viejas, con posterior quema de zonas amarillentas, reducción del crecimiento, en casos severos ocurre también defoliación
Azufre	Clorosis general del follaje, reducción del crecimiento.
Hierro	Amarillamiento general de hojas nuevas, hojas pequeñas
Cobre	Deformación y amarillamiento de hojas nuevas, iniciando en puntas de hojas.
Zinc	Clorosis intervenal de hojas nuevas, con aparición de manchas necróticas.
Manganeso	Coloración verde pálida en hojas nuevas con tendencia a amarillearse, manchas necróticas pequeñas en hojas nuevas.
Boro	Puntas de hojas nuevas se tornan amarillentas. Deformación y corrugamiento de hojas nuevas, muerte de puntas en crecimiento.





Appendix 2. Calendar of conventional and organic inputs turned in to farmers

	Producer			
	CONVENTIONAL			
Date	**Carlos**	**Enrique**	**Benedicto**	**Celso**
April 23 2015	Agriful, Agriver, Safsan	Agriful, Agriver, Safsan	Agriful, Agriver, Safsan	Agriful, Agriver, Safsan
May 22 2015	Calcio, formula multimineral, 18-05-15, Hidrocomplex, Kmag, Confidor, Carbendozim, Silvacur, mancozeb, Curzate, Agry-gent, Serenade, Oxicloruro de Cobre	Calcio, formula multimineral, 18-05-15, Hidrocomplex, Kmag, Confidor, Carbendozim, Silvacur, mancozeb, Curzate, Agry-gent, Serenade, Oxicloruro de Cobre	Calcio, formula multimineral, 18-05-15, Hidrocomplex, Kmag, Confidor, Carbendozim, Silvacur, mancozeb, Curzate, Agry-gent, Serenade, Oxicloruro de Cobre	Calcio, formula multicismineral, 18-05-15, Hidrocomplex, Kmag, Confidor, Carbendozim, Silvacur, mancozeb, Curzate, Agry-gent, Serenade, Oxicloruro de Cobre
June 1 2015			Ridomil	
July 2 2015		Regent, Ridomil		Ridomil
August 7 2015	Spintor			
	ORGANIC			
	Daniel	**Rosa**	**Edgar**	**Jorge**
April 23 2015	Bokashi	Bokashi	Bokashi	Bokashi
May 15 2015	Trichoderma 2 bolsas, chili picante, Biofeed Start 1 litro, Biofeed Calidad 1 litro, Fructiplus 1 litro	Trichoderma 2 bolsas, chili picante, Biofeed Start 1 litro, Biofeed Calidad 1 litro, Fructiplus 1 litro	Trichoderma 2 bolsas, chili picante, Biofeed Start 1 litro, Biofeed Calidad 1 litro, Fructiplus 1 litro	Trichoderma 2 bolsas, chili picante, Biofeed Start 1 litro, Biofeed Calidad 1 litro, Fructiplus 1 litro
May 21 2015	Bacillus Thurigencis, plastico para techo	Bacillus Thurigencis, plastico para techo	Bacillus Thurigencis, plastico para techo	Bacillus Thurigencis, Plastico para techo
June 1 2015	Trichoderma 2 bolsas, gallinaza	Trichoderma 2 bolsas, gallinaza	Trichoderma 2 bolsas, gallinaza	Trichoderma 2 bolsas, gallinaza
June 12 2015	PSD, Sulfocalcio	PSD, Sulfocalcio	PSD, Sulfocalcio	PSD, Sulfocalcio
June 17 2015	Sulfato de Magnesio, Sulfato de Potasio, Mezcla zinc/boro, calcio	Sulfato de Magnesio, Sulfato de Potasio, Mezcla zinc/boro, calcio	Sulfato de Magnesio, Sulfato de Potasio, Mezcla zinc/boro, calcio	Sulfato de Magnesio, Sulfato de Potasio, Mezcla zinc/boro, calcio

July 23 2015	BT, Bokashi, Fertilizante Organica, trichoderma	BT, Bokashi, Fertilizante Organica, trichoderma	BT, Bokashi, Fertilizante Organica, trichoderma	BT, Bokashi, Fertilizante Organica, trichoderma
August 7 2015	SulfoCalcio, PSD	SulfoCalcio, PSD	SulfoCalcio, PSD	SulfoCalcio, PSD
September 16 2015	SulfoCalcio, PSD, chili picante	SulfoCalcio, PSD, chili picante	SulfoCalcio, PSD, chili picante	SulfoCalcio, PSD, chile picante
September 30 2015	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD
October 13 2015	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD
October 28 2015	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD	Trichoderma, Sulfocalcio, PSD

Appendix 3. Management guidelines for tomato and sweet pepper crops

Buenas Prácticas para el manejo de Chile y Tomate

Proyecto de siembra de tomate y chile dulce con CATIE

Indicaciones generales para prevenir plagas y enfermedades

- Se debe realizar un muestreo al menos 2 veces por semana para detectar plagas y enfermedades siempre y cuando sea necesario. En los casos donde una plaga o enfermedad tenga probabilidades de aparecer, según la historia de la finca es probable que debamos implementar control preventivo. Cada caso va a ser controlado por separado.
- Para llevar ese control es muy importante muestrear 2 veces por semana para ver la posible presencia de plagas y enfermedades tanto en cultivos de interés como en los cultivos y plantas alrededor de las parcelas del ensayo.
- El personal que elimine las plantas con síntomas de virosis, debe lavarse las manos antes de realizar otra tarea para evitar posibles contagios.
- Si fuma cuando está en la finca, es muy importante que se lave las manos antes de examinar las plantas.
- Evite provocar heridas y rasguños a las plantas y sus raíces.
- Si se va a usar control biológico, debe hacerlo 10 días antes o después de la aplicación de cualquier producto químico.
- Control biológico y la aplicación de material orgánica generalmente está permitido en agricultura orgánica hasta un cierto nivel. En este ensayo cada caso será determinado por separado.

CHILE DULCE

Condiciones de los suelos:

- Para el cultivo del chile se recomiendan suelos livianos, de textura areno-arcillosos, un buen drenaje y moderado contenido de materia orgánica.
- En el caso de suelos arcillosos deben tener buen drenaje y estar bien preparados antes de la siembra para evitar acúmulos de agua que favorecen la incidencia de enfermedades en la raíz.

Riego:

- Para obtener rendimientos elevados, se necesita un suministro adecuado de agua y suelos relativamente húmedos durante todo el período vegetativo.
- Antes de la floración y al inicio de los primeros brotes florales de la plantación, el cultivo es más sensible a la falta o exceso de agua. La deficiencia de agua en el suelo reduce el crecimiento y desarrollo de la planta; en cambio el exceso reduce la tasa de absorción.

Poda

- Algunos cultivos de chile dulce, casi no requieren poda, limitándose ésta a la supresión de los brotes que nacen desde el nivel del suelo hasta la primera bifurcación. El aclareo de frutos consiste en suprimir los que presentan algún defecto que los inutiliza para la comercialización.
- Una poda muy poco utilizada pero de excelentes resultado en la producción de mayor cantidad de frutos por planta consiste en eliminar la primera flor cuajada de la planta. Esta práctica no solo estimula la floración sino que también el número y el peso de los frutos por planta aumentan notoriamente.

Amarre:

- Durante la siembra y el amarre de las plantas, todas las herramientas deberán estar desinfectadas para evitar la propagación de enfermedades.
- Se puede usar postes de bambú, madera u otro material, separados 2.5 a 3 metros entre sí.
- El primer hilo de alambre se coloca entre 60 a 80 cm de altura y en él se amarra el tallo principal de la planta; el segundo hilo está a una altura entre 1 y 1,20 m, y sirve para amarrar todas las ramas y evitar que se quiebren.

TOMATE

Condiciones de los suelos:

- De preferencia suelos francos con buen contenido de materia orgánica pero produce muy bien en suelos pesados hasta suelos arenosos con materia orgánica baja.

Riego:

- Existen diversos sistemas de riego (gravedad, aspersión y goteo) y su uso depende de la disponibilidad de recursos, pendiente del terreno, textura de suelo, abastecimiento y de agua. Con cualquiera de los sistemas seleccionados, se debe evitar someter el cultivo a deficiencias o excesos de agua. Es importante la buena distribución del riego durante todo el ciclo del cultivo, principalmente antes de la formación de frutos.
- En cuanto al manejo del riego, es necesario considerar el desarrollo del cultivo, es decir que el tiempo de riego diario dependerá del tamaño de la planta, necesitándose regar muy poco tiempo recién trasplantado el cultivo e ir aumentando el tiempo de riego según sea el crecimiento de la planta.

Amarre:

- Durante la siembra y amarre, todas las herramientas deberán estar desinfectadas para evitar la propagación de enfermedades.
- El primer amarre se coloca a los quince días después del trasplante mientras que los subsiguientes cada 10 días uno de otro hasta 10 diez días antes de cosecha.
- Los postes pueden ser de caña de bambú o del material que más se disponga en la zona
- Las estacas se deben de colocar cada 1.0 metros (3.3’) a 1.2 metro (4’) de distancia entre estacas siendo la distancia más corta donde tenemos plantas más grandes y rendimientos más altos.
- La altura de la estaca depende de la variedad usada y van desde 1.2 mts (4’) a 2 mts (6.5’)
- El amarre suele realizarse con hilo de polipropileno (rafia) sujeto de un extremo a la zona basal de la planta (liado, anudado o sujeto mediante anillas) y de otro a un alambre situado a determinada altura por encima de la planta (1,8-2,4 m sobre el suelo). Conforme la planta va creciendo se va sujetando al hilo tutor mediante anillos, hasta que la planta alcance el alambre.

Destallado:

- La poda inicial es efectuada cuando la planta tiene cerca de 40 cm de altura e inicia la emisión de brotes laterales. En esta poda se seleccionan los mejores dos o tres tallos de la planta y se elimina el resto, a la vez que se hace una deshoja para eliminar las hojas enfermas que se encuentran en contacto con el suelo.
- Consiste en la eliminación de brotes axilares para mejorar el desarrollo del tallo principal. Debe realizarse con la mayor frecuencia posible (semanalmente en

verano-otoño y cada 10-15 días en invierno) para evitar la pérdida de biomasa fotosintéticamente activa y la realización de heridas. Los cortes deben ser limpios para evitar la posible entrada de enfermedades. En épocas de riesgo es aconsejable realizar un tratamiento fitosanitario con algún fungicida-bactericida cicatrizante, como pueden ser los derivados del cobre.

Deshojado:

- Es recomendable tanto en las hojas más viejas, con objeto de facilitar la aireación y mejorar el color de los frutos, como en hojas enfermas, que deben sacarse inmediatamente eliminando así la fuente de inóculo.

Desbrote:

- El desbrote o deshija consiste en el corte sistemático y frecuente de los numerosos brotes laterales que surgen en las axilas de las hojas, por debajo de la primera horqueta.
- Tal operación se efectúa una o dos veces por semana, empujando y quebrando los brotes, tan pronto alcancen un tamaño suficiente para ser agarrados. No es conveniente el uso de instrumentos cortantes ni de las uñas, pues se propagan enfermedades con mayor facilidad.

Appendix 4. Score sheet for farmer management aspects of interest

Evaluación de Manejo en los lotes del estudio

Nombre del productor ________________________Fecha de evaluación________________

La clasificación se usa para describir la calidad de manejo que cada productor está dando al lote del estudio. Se usa la siguiente clasificación:

1- Muy mal

3- Mal

5- Intermedio

7- Bueno

9- Muy Bueno

Manejo de malezas (   )

Calidad del techo (   )

Altura del lomillo (   )

Aplicación oportuna de los insumos entregados (   )

Manejo de plagas y enfermedades por su propia cuenta (   )

Deshijar (   )

Amarrar (   )

Quitar hojas y frutos enfermos de la planta (   )

Quitar partes enfermas de la planta del área del estudio (   )

Drenaje de aguas (   )

Cosecha oportuna de los frutos (   )

Observaciones o comentarios:

Appendix 5. Participatory evaluation of tomato and sweet pepper varieties

Clasificación de variedades de Chile

Los productores ordenar cada variedad entre menos deseables y más deseables. Para empezar identificar la variedad más deseable y menos deseable para usar como referencias. Tomar foto del orden de cada productor.

Clasificar cada variedad individualmente:

1=muy mal

3= mal

5= intermedio

7=bueno

9= muy bueno

Chile	**Clasificación (1, 3, 5, 7, 9)**	**Características mas preferidas**	**Carácterísticas menos preferidas**	**Sembrará de nuevo? (Si o No)**	**Por qué? (Oportunidad en el mercado, auto-consumo…)**
18757					
15661					
17268					
9777					
17151					
18660					
19259					
032170					
1247					
Natalie					
4212					
9814					

Clasificar cada variedad individualmente por características preferidas:

1=muy mal

3= mal

5= intermedio

7= bueno

9= muy bueno

	Variedad											
Características Preferidas	**18757**	**15661**	**17268**	**9777**	**17151**	**18660**	**19259**	**32170**	**1247**	**Natalie**	**4212**	**9814**
Mayor rendimiento												
Buen tamaño del fruto												
Buena para el mercado												
Piel gruesa												
Fruto largo												
Aguanta mucha lluvia												
Menos días hasta floración												
Fruta dura más despues de la cosecha												
Fruto con carne grueso												
Fruto jugoso												
Buen sabor												
Planta tiene buena altura												
Buen color de la fruta												
Fruta firme												
Bien Adaptada al ambiente de la finca												
Bien adaptada al clima												
Otro:												
Otro:												

4. Clasificar cada variedad individualmente por incidencia de plagas y enfermedades:

1= Muy bajo

3= Bajo

5= Medio

7= Alto

9= Muy alto

Plagas y enfermedades	**18757**	**15661**	**17268**	**9777**	**17151**	**18660**	**19259**	**32170**	**1247**	**Natalie**	**4212**	**9814**
Tizon Tardio												
Tizon Tempraño												
Maya												
Fusarium												
Bacteriosis en la fruta												
Mancha Cercospera												
Molde Gris												
Virus												
Picudo												
Mosca Blanca												
Minador												
Otro:												
Otro:												

Clasificación de variedades de Tomate

Los productores ordenar cada variedad entre menos deseables y más deseables. Para empezar identificar la variedad más deseable y menos deseable para usar como referencias. Tomar foto del orden de cada productor.

Clasificar cada variedad individualmente:

1=muy mal

3= mal

5= intermedio

7=bueno

9= muy bueno

Tomate	Clasificación (1, 3, 5, 7, 9)	Características mas preferidas	Características menos preferidas	Sembrará de nuevo? (Si o No)	Porque? (Oportunidad en el mercado, auto-consumo…)
5515					
5640					
10596					
20485					
20547					
20553					
17358					
17330					
1426					
1424					
JR					

4. Clasificar cada variedad individualmente por características preferidas:

1=muy mal

3= mal

5= intermedio

7=bueno

9= muy bueno

	Variedad										
Características Preferidas	**5515**	**5640**	**10596**	**20485**	**20547**	**20553**	**17358**	**17330**	**1426**	**1424**	**JR**
Mayor Rendimiento											
Buen tamaño del fruto											
Buena para el mercado											
Piel grueso											
fruto dulce											
Aguanta mucha lluvia											
Menos días hasta floración											
Fruta dura mas después de la cosecha											
Fruto con carne más carnoso											
Fruto bien rojo											
Fruto jugoso											
Buen sabor											
Planta tiene buena altura											
Fruta firme											
Bien Adaptada al ambiente de la finca											
Bien adaptada al clima											
Otro:											
Otro:											

5. Clasificar cada variedad individualmente entre 1-9 por incidencia de plagas y enfermedades:

1= Muy bajo

3= Bajo

5= Intermedio

7= Alto

9= Muy alto

	Variedad										
Plagas y enfermedades	**5515**	**5640**	**10596**	**20485**	**20547**	**20553**	**17358**	**17330**	**1426**	**1424**	**JR**
Tizon Tardio											
Tizon Temprano											
Bacteriosis en la fruta											
Fusarium											
Maya											
Minador											
Mosca Blanca											
Mildue											
Otro:											
Otro:											

Appendix 6. Final farmer interview

Fecha______________________

1. Datos personales

a. Nombre del productor ________________________________
b. Usted es parte de una asociación/grupo de productores?
c. Qué grupo?
d. Cómo funciona el grupo (ej: diferentes productores producen diferentes cultivos o todos pueden producir lo que sea?)
e. Cuál es su papel en la finca?
f. Cuál es el cultivo principal de la finca?
g. Que porcentaje de tiempo usa usted trabajando en este cultivo por semana?
h. En caso que café no es cultivo principal; cual él es rol de café en la finca, y que porcentaje de tiempo usa usted trabajando en café por semana?
i. Cuál es su fuente principal de ingresos?
j. Cuáles son sus mayores gastos?
k. Hay otras personas ayudando con mano de obra en la finca?

2. Información sobre la finca

a. Cuál es el tamaño de su finca?
b. Qué experiencia ha tenido usted con el manejo de hortalizas?
c. Por cuánto tiempo?
d. Qué retos tiene en la finca actualmente? (demasiada lluvia, menos lluvia, retos económicos, acceso al mercado, rendimiento, alta o baja producción, problemas con el suelo, etc.) Y cuales ha tenido en los últimos 5 años?

3. **Diversificación general**

a. Cuales son las razones principales para diversificar o no diversificar la finca, con cultivos nuevos, además del café?
b. Que herramientas, como tecnologías, capacitaciones, talleres, etc) le ayudarían a diversificar la finca con nuevos cultivos?
c. Que otros incentivos le ayudarían a diversificar la finca con nuevos cultivos?
d. Cree que participar en proyectos como esto de evaluación participativa de diferentes cultivos y variedades le motiva a usted a diversificar con nuevos cultivos? Porque?

4**. Evaluación participativa de las hortalizas evaluadas**

a. Porque decidió Usted participar en este proyecto?
b. Cuál es su interés en tomate y chile dulce? O porque estabas interesado en sembrar tomate y chile?
c. Que son sus percepciones generales de las variedades evaluadas?
d. Su experiencia con este proyecto va a influenciar sus decisiones en el futuro de diversificar o no diversificar la finca con nuevas variedades? Como?
e. Desea seguir cultivando alguna variedad evaluada el siguiente año? En caso que sí, cual(es)?

5. Semillas

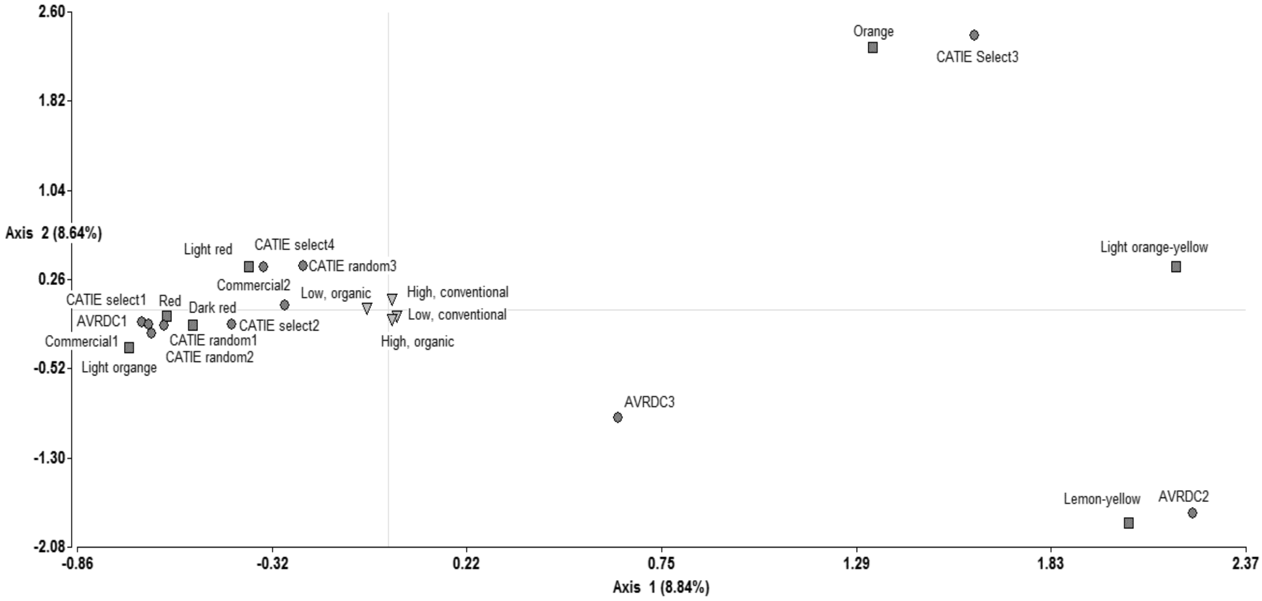
a. Como consigue Usted normalmente semillas de hortalizas?
b. Como cree usted que se podría mejorar la oferta de variedades en general? Como en su comunidad o en Turrialba en general?
c. Qué opina usted del banco de semillas de CATIE para conseguir semillas?

6. Percepciones del proyecto

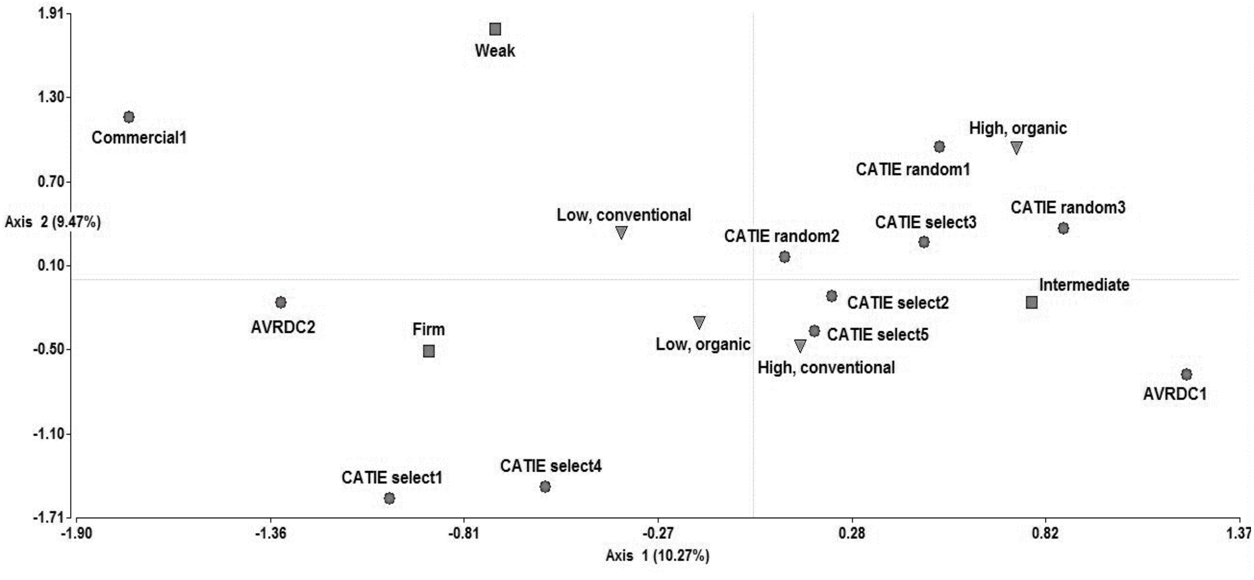
a. Cuales cosas le ha gustado y no le ha gustado de este proyecto? Porque?
b. Que beneficios obtuvo usted del proyecto?
c. Que costos incurrió usted para participar en este proyecto?
d. Los beneficios fueron más que los costos?
e. Usted participaría en otro proyecto similar?
f. Como se puede mejorar el proceso de este proyecto?
g. Usted tiene algunos comentarios finales sobre el proyecto?

Appendix 7. Correspondence analyses of relationships between tomato and sweet pepper varieties and qualitative descriptors of importance

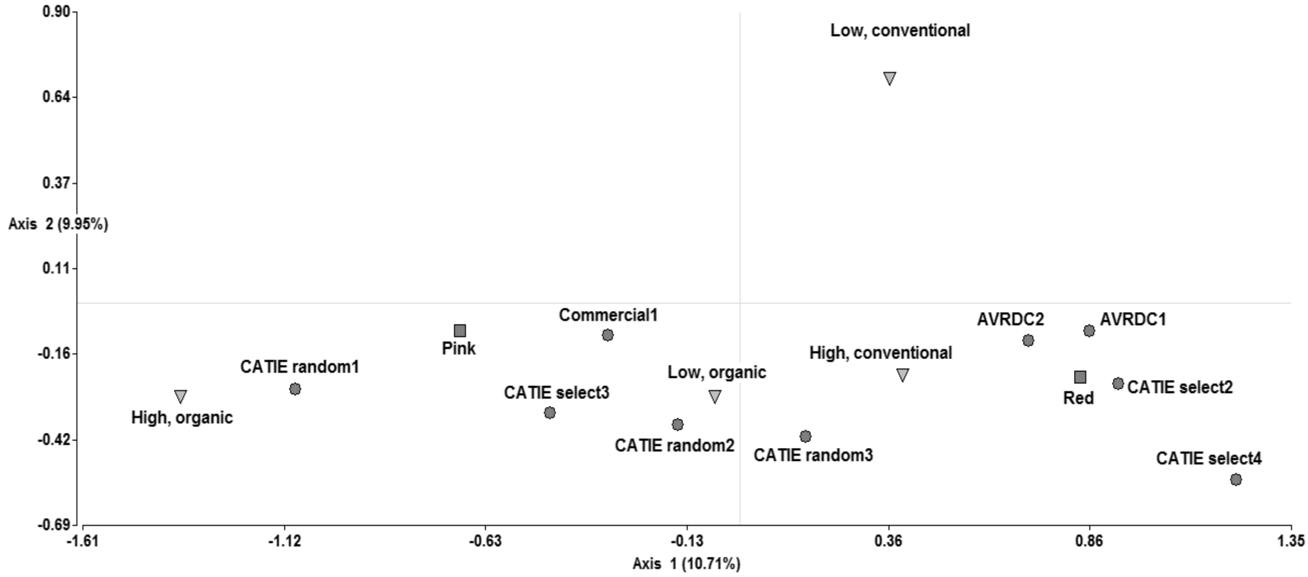
a. Tomato varieties and color of fruit pulp



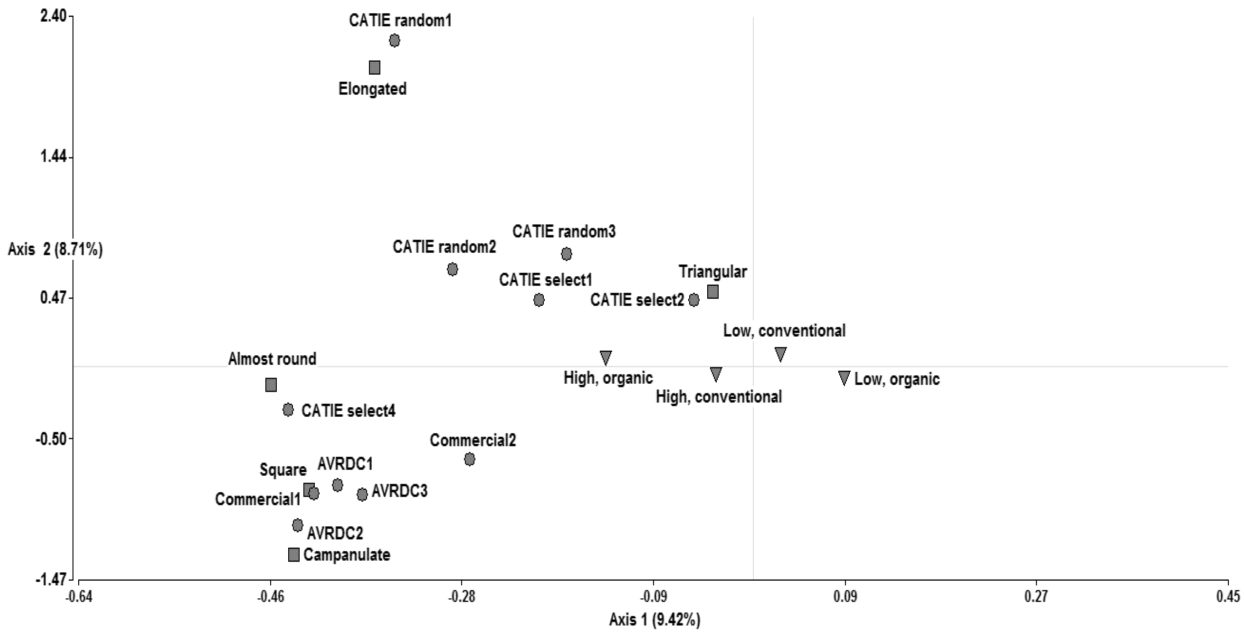
b. Tomato varieties and fruit firmness



c. Sweet pepper varieties and color of mature fruit

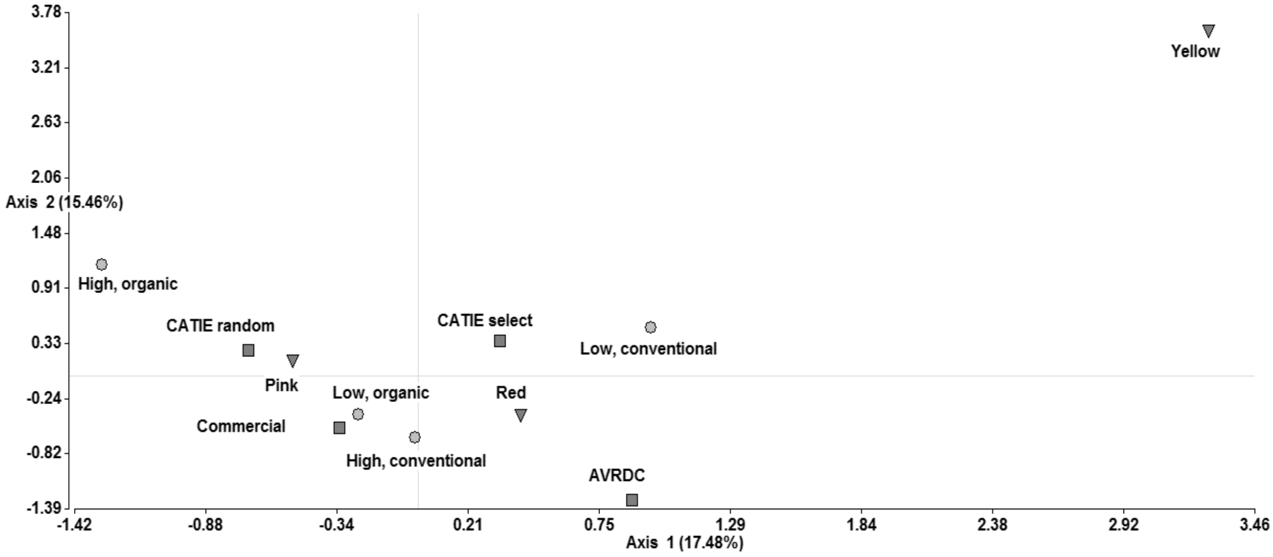


d. Sweet pepper varieties and fruit form of mature fruit

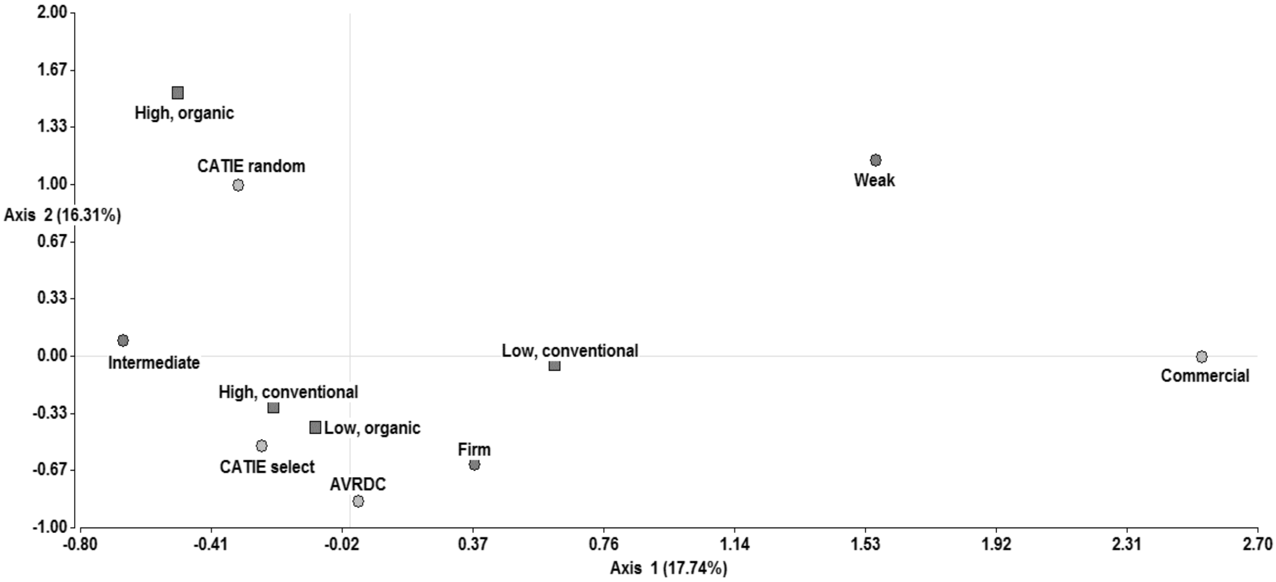


Appendix 8. Correspondence analyses between tomato and sweet pepper groups and qualitative traits of interest

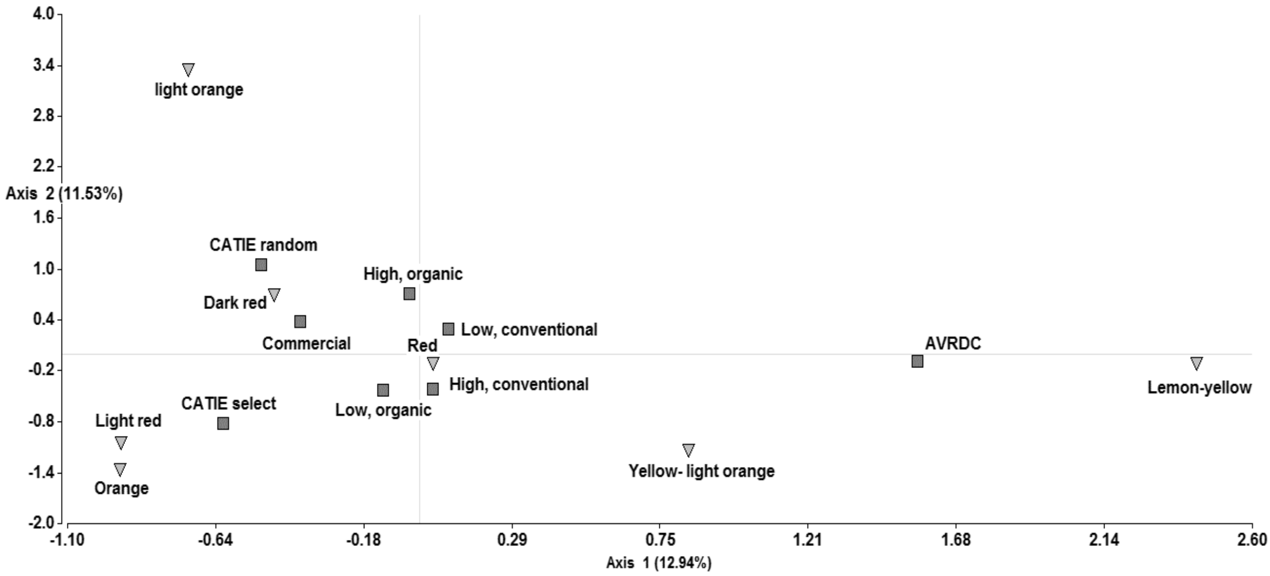
a. Tomato groups and fruit pulp color



b. Tomato groups and fruit firmness



c. Pepper groups and fruit color:



d. Pepper groups and fruit form