AMERICAN UNIVERSITY OF BEIRUT

HORTICULTURAL PERFORMANCE OF FIVE OPEN-POLLINATED TOMATO VARIETIES UNDER ORGANIC MANAGEMENT

by
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A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science
to the Department of Plant Science
of the Faculty of Agriculture and Food Science
at the American University of Beirut

Beirut, Lebanon
February 2020

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ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor Dr. Mirella Aoun for her continuous support and guidance throughout this process; Dr. Aoun's door was always open, sacrificing so much time and energy to help me reach my goal. Your patience, encouragement and confidence in me meant more than I can express, and I am forever grateful.

I would also like to extend my sincere thanks to my co-advisor Dr. Yusef Abou Jawdeh, who always provided support and encouragement. I am gratefully indebted to you for your valuable comments and help on this paper.

A thank you to my committee members Dr. Amar Olabi and Dr. Imad Toufieli for their support.

Dr. Houssam Shaib and Hana Sobh were also great sources of help during this time. Dr. Shaib sacrificed so much of his personal time to which I am immensely appreciative. Hana was always there when I needed support both academically and emotionally so thank you.

I would like to thank the most important people in my life. To my family who continuously supported me and believed in me even on my darkest days. All this would not have been possible without you.

To Ornella, thank you for being my emotional support system all the way from Cyprus.

Finally, to Naji, you were my rock, my support system and so much more. I wouldn't have been able to survive this without you and I am eternally grateful.

AN ABSTRACT OF THE THESIS OF

Rachel Pierre Sfeir for Master of Science
Major: Plant Science

Title: Horticultural Performance of Five Open-Pollinated Tomato Varieties under Organic Management

A large proportion of commercially grown tomato cultivars were developed and adapted to high input conventional agriculture systems, which employ synthetic chemicals in their production systems. There is a need to develop cultivars that are adapted to local conditions and to the challenges of a low-input or organic production system. Based on information gathered from organic farmers and consumers surveys collected prior to the experiment, we set objectives for a tomato variety trial under organic management in Mediterranean conditions. Few of the issues that hamper the production and trade expansion of organic tomato are the lack of cultivars specifically adapted to organic conditions, the shelf life differences between organic and conventional tomato and the susceptibility of the crop to pests and pathogens. The aim of the trial was to assess the horticultural performance of five varieties under organic management, three of which were locally bred lines and two are commercially sold for organic production. The trial consisted of a randomized complete block design with 12 plants per row, 5 rows per block and 3 blocks (reps) and was set in a certified organic farm in Mount Lebanon. We monitored the yield and productivity of each variety, its susceptibility to pests and physiological disorders, its phenological characteristics, and the quality of its production at harvest and its quality after storage. Sensory evaluation was also performed on a group of semi-trained consumers and a culinary chef to determine consumer appreciation of each variety. Overall, lines AUB1 and AUB3 were better than the commercially sold varieties in terms of yield, producing 55.44 t/ha and 53.62 t/ha respectively while AUB2 produced better than Indigo, producing 20.06 t/ha. As for susceptibility, AUB2 did better than the commercially imported varieties in terms of being the least susceptible to pea leafminer with 14.9% and fruit zippering with 0.133 while AUB3 was similar to Indigo for susceptibility to physiological disorders.

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ABBREVIATIONS

10x	10 times
&	And
-	Minus
%	Percent
+	Plus
±	Plus or minus
Av.	Average
BER	Blossom end rot
B	Blue
BHT	Butylated hydroxytoluene
cm	Centimeter
C	Conventional
D0	Day 0
D6	Day 6
D8	Day 8
DNA	Deoxyribonucleic acid
^oC	Degrees Celsius
DW	Dry Weight
du	dunum
Etc.	Et cetera
EB	Evolutionary Breeding
FAFS	Faculty of Agriculture and Food Sciences

GMO(s)	Genetically modified organism(s)
g	Gram(s)
G	Green
GH	Greenhouse
ha	hectare
Hg	hectogram
in	Inch(s)
Kgs	Kilogram(s)
LBP	Lebanese Pounds
L	Liter
m	Meter
Mt	metric ton
µg	Microgram
meq	Milliequivalent
mg	milligram
ml	Milliliter(s)
mm	Millimeter(s)
mins	Minute(s)
nm	Nanometer(s)
N	Normal
Nbr or #	Number
OP	Open pollinated
O	Organic
OF	Organic Farming

OPB	Organic Plant Breeding
oz	Ounce
PPB	Participatory Plant Breeding
PPV	Participatory Varietal Selection
K	Potassium
lb	Pound(s)
q	Quintal
R	Red
RH	Relative Humidity
rpm	Revolutions Per Minute
cm^2	Square centimeter
m^2	Square meter
Std	Standard
t	Tons
TSS	Total Soluble Solids
UV	Ultraviolet
X-ray	X- radiation

CHAPTER 1

INTRODUCTION

Tomato (*Solanum lycopersicum*) is one of the most popular vegetables worldwide, with a global production estimated at 188 million tons in 2018. Tomato is globally grown for its edible fruits rich in antioxidants with many health benefits. This fruit can be consumed fresh or in several processed forms including dried, puree, sauce and soup (Rocha et al., 2013). It has been reported that the consumption of raw tomato and tomato-based products is associated with reduced risk of cancer and cardiovascular diseases (Giovannucci, 1999).

A large proportion of commercially grown tomato cultivars have been developed and adapted to conventional agriculture systems, that use synthetic chemicals in their practices (Brady, 2011). However, there is an increase in the demand for organic products due to a rise in the number of customers who are in search of healthier, tastier and more environmentally friendly foods. This has led to an increase in organic farming and thus a need for cultivars that are bred under organic practices for organic farming. Organic farming has emerged in the second half of the last century as an alternative to the negative externalities of industrial agriculture (Campanelli et al., 2015). Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (Luttikholt, 2007).

One of the main arguments used against organic farming is that yields under organic systems are lower than in conventional agriculture. An estimated 95% of varieties grown on organic farms are not bred for organic environments, and research has shown that varieties developed in conventional systems often under-perform in organic systems (Lammerts van Bueren et al., 2011) (Hoagland et al., 2015). Thus, there is a major need to develop and breed cultivars specifically for organic production that are adapted to local conditions and produce higher yields, as well as trials to test these varieties under different climates ((Sidhu & Nandwani, 2017). Variety evaluation is one area that can be helpful for organic producers. Several such studies have been conducted by researchers around the world examining different aspects of variety performance under organic conditions. Cultivars have been evaluated in Italy, India, Spain, Croatia, Poland, France and the United States (Francis & Stark, 2012); (Ganesan, 2001); (Gonzalez-Cebrino et al., 2011); (Sánchez-Giráldez et al., 2010). In one study, the production of organic tomato, when compared to the conventional production, presented a cost 17.1% lower and profitability 113.6% higher (Toledo, Costa, Bacci, Fernandes, & Souza, 2011). Furthermore, consumers of organic products accept non-standard fruits with different shapes and colors and are willing to pay more for them (Toledo et al., 2011).

The purpose of this study was to assess the performance of five open pollinated tomato varieties grown under organic practices in a Mediterranean climate. Three are locally bred at the American University of Beirut and have only been tested in greenhouses before this trial. While the other two, are international varieties bred for organic farming systems. Cherokee purple is an heirloom cultivar and Indigo rose was bred at Oregon State University to have higher levels of antioxidants. The parameters that were specifically focused on and evaluated included:

1. the production and productivity of each variety
2. phenological development and plant vigor
3. days to maturity
4. tolerance to pests
5. fruit quality including lycopene content
6. fruit quality after storage
7. fruit flavor appreciation by semi-trained consumers

CHAPTER II

LITERATURE REVIEW

A. Tomato production in Lebanon

Tomato is a major cash crop in Lebanon, with the total production increasing over the years from 30,000 tons in the early 60s to 300,157 tons in 2018 (fig 2). The average yield per hectare has also increased from 13.04 tons/ha in the early 60s to 78.78 tons/ha in 2018 (fig 1), which may be correlated with the improved cultural practices, importation as well as the introduction of high yielding varieties. However, not necessarily due to the significant increase in the cultivated area which has merely doubled while the yield has increased by six folds (fig 3) (FOASTAT, 2017).

Tomatoes are grown on 1,665.8 hectares of farmland in the Bekaa region with approximately 22% grown in greenhouses. This represents under 2% of the farmland in the region but 38% of tomatoes grown nationally. Lebanon produces 7 tons of tomatoes per dunum harvested from both greenhouses and open field, based on FOASTAT (statistics and interviews). Thus around 116,606 tons of tomatoes were harvested in the Bekaa in 2010 (MercyCorps, June 2014). Based on customs data, the Lebanese population consumed 295,741 tons of tomatoes and waste was estimated at 7-10%, which falls within the acceptable range for agriculture standards (MercyCorps, June 2014).

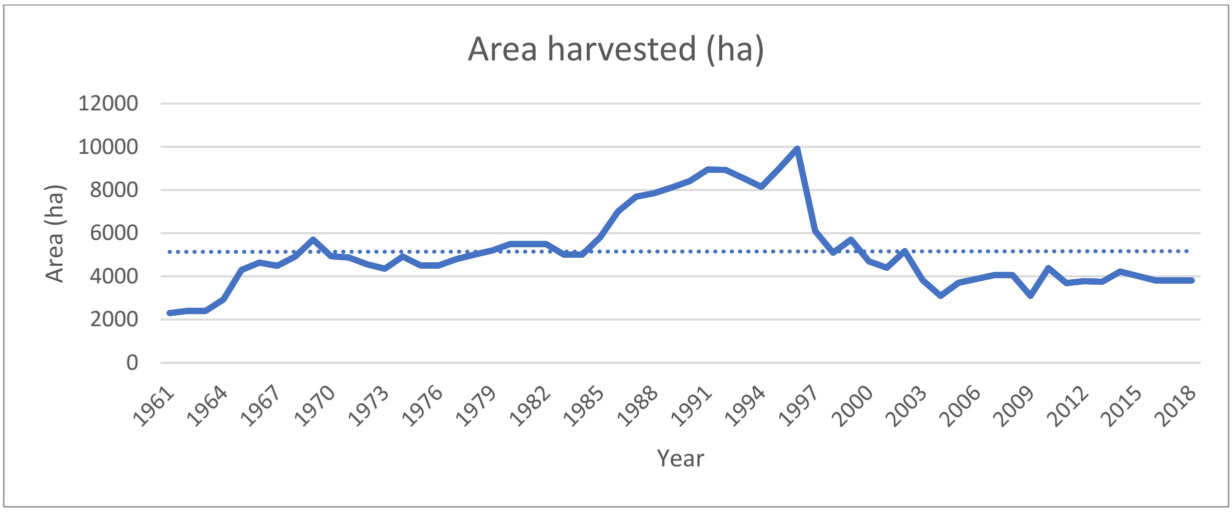


Figure 1. Total yearly area planted with tomato in Lebanon between 1961 and 2018

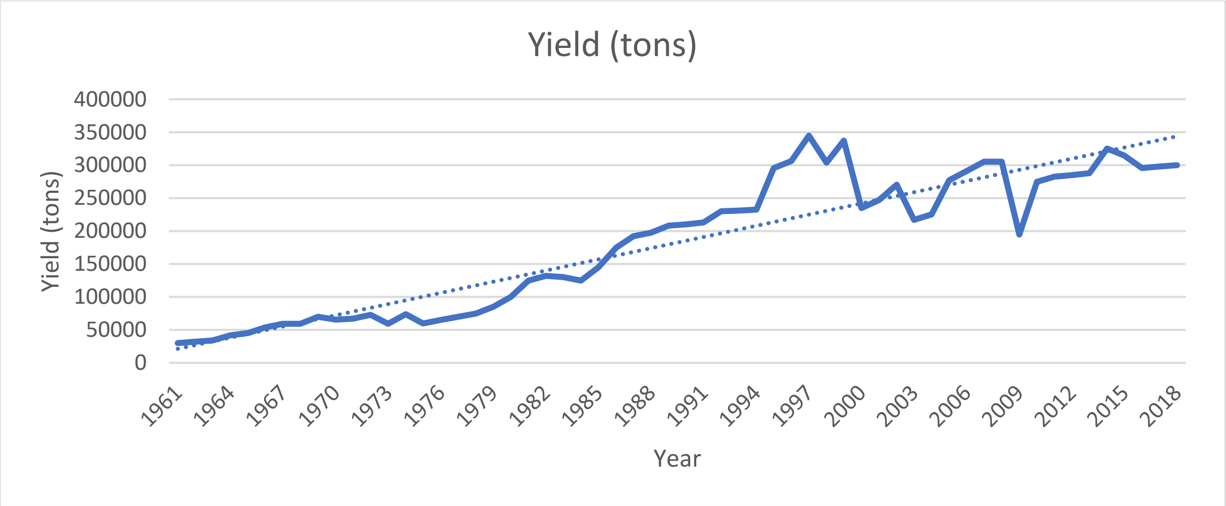


Figure 2. Total yearly yield in tons/ha between 1961 and 2018 for Lebanon

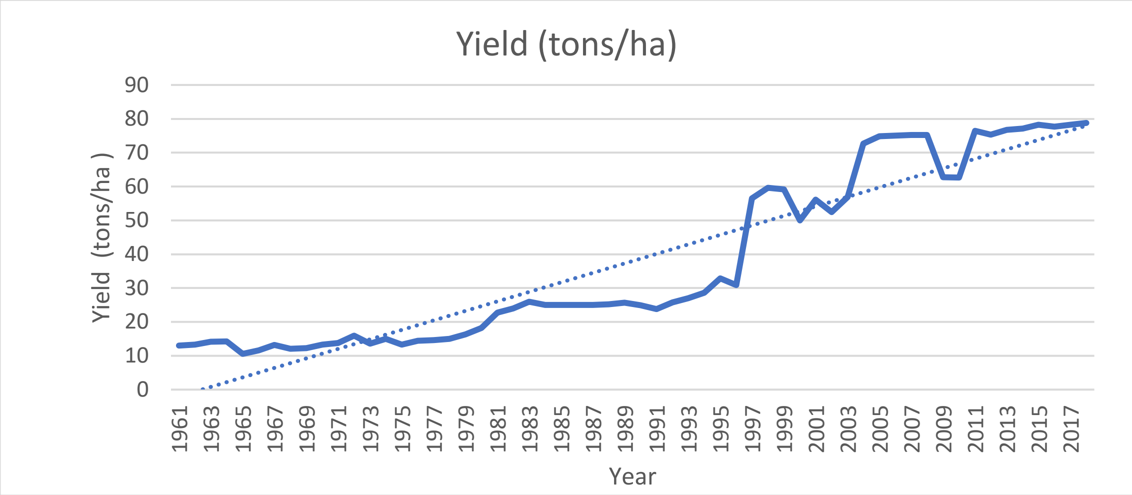


Figure 3. Total yearly yield in tons between 1961 and 2018 for Lebanon

B. Importance of assessing new varieties in organic production

The demand for organic products has been increasing in the recent years due to consumers' concerns about health and the environment which gave a push to the organic farming system. However, an overwhelming 95% of the varieties grown on organic farms are not bred for this system, rather were conventionally bred. Seeds from conventionally bred varieties can be certified as organic as long as they do not come from cultivars that are genetically engineered nor developed using cell fusion (Desclaux, 2005). Cultivars bred under conventional practices are often bred in high input systems with the use of chemicals and pesticides, which is the opposite of the practices used in low input organic farming. Research has shown that varieties developed in conventional systems often under-perform in organic systems (Lammerts van Bueren et al., 2011). This is a main issue that affects organic production and could be a cause in the yield gap between the two systems. Among other factors include the shelf life difference (Toledo et al., 2011) and the susceptibility of the crop to pests and pathogens (Toledo et al., 2011). This shows that there is a need to breed varieties under organic practices for organic farmers, more so for organic agriculture to be able to continue growing as a viable sector of the food system. Another important aspect is the assessment of these new cultivars in variety trials, specifically in organic trials. Variety evaluation is very helpful to organic farmers as it evaluates different aspects of the variety performance as shown by several studies around the world including Italy, Spain, Poland, France and the United States (Francis & Stark, 2012); (Ganesan, 2001); (Gonzalez-Cebrino et al., 2011); (Sánchez-Giráldez et al., 2010). Assessing these new varieties via trials also helps to evaluate their adaptability to the region and practices as well as target traits that could be improved or added. According to Toledo, (2011), evaluating varieties within the same soil and climate allows farmers to compare them in terms of potential productivity, fruit quality and resistance to pests and pathogens. The same variety can also perform differently in different regions since it possesses diverse genetic traits that determine greater or less sensitivity to environmental conditions and other factors of production, this is also known as genotype by environment (GxE) interaction. Thus, it is essential to evaluate cultivars in several regions in order to be able to select the ones most suitable in each.

A number of characteristics other than yield are evaluated in these trials including fruit cracking, antioxidants such as lycopene, sugar and vitamin C content (Aldrich et al., 2010). Other aspects that should also be highlighted include soil nutrient use efficiency, weed competition, insect resistance, rhizosphere competence for disease resistance, abiotic stress tolerance and fruit quality as suggested by Lammerts van Bueren et al., (2011).

C. Attributes assessed in organic tomato trials

Since the topic of this paper concerns the organically grown tomato, it makes sense to dive into the specific attributes that are focused on when breeding improved tomato varieties for organic farmers. First, the tomato fruit is considered to be very beneficial health wise, a functional food in other terms, since it provides a substantial source of vitamin C, flavonoids, carotenoids and phenolic compounds to the human diet (Watson, 2003).

Low-input organic farms are known to be heterogenous in terms of soil, weed pressure, climate and fertility management practices that is why some breeders select varieties for "broad adaptability" so the cultivars can perform well in multiple environments and under different climates. However, this means that they tend to eliminate varieties (genetic material) that do not exhibit a wide range of adaptability, which in turn could result in removing unique attributes that are important in improving crop performance in organic farms (Dawson, Murphy, & Jones, 2008). When breeding new varieties, it is important to remember what traits are crucial for their success in the field as well as the traits that are looked for by consumers in the market.

There are specific traits that growers look for when breeding tomato varieties, some are more important than others and might differ between organic and conventional growers. However, the top two attributes that are similar for both, organic and conventional, include fruit yield and flavor. Fruit yield can be divided into total, marketable and unmarketable yield. The total yield is measured by weighing the harvested fruits on a digital balance, followed by their distribution into marketable and unmarketable respectively. As for flavor, this specific attribute is difficult to breed for as it is subjective and depends on the growers and consumers preferences. However, flavor includes total soluble solids (TSS) and acid content, TSS gives the fruit its sweet taste and can be measured using a handheld refractometer (by placing a few drops of the juice extract on the prism) (Aldrich, 2010). While the acidity is measured by titrating extracted tomato juice against 0.1N NaOH using phenolphthalein as an indicator (Panchal Bhakti, 2017). Flavor could be assessed through sensory evaluation surveys using a hedonic scale or descriptively.

Nutritional quality seems to be an important attribute as well, especially for organic growers. It is comprised of carotenoids, ascorbic acid (vitamin C), protein and lycopene content among others. Lycopene content can be determined using spectrophotometry, read at an absorbance of 503 nm. Ascorbic acid content can be determined using a high-performance liquid chromatography (HPLC) and read at an absorbance of 254 nm. The concentration is then calculated using the following formula $\lambda = \frac{E}{3{,}15} x \ \frac{20}{m}$ where, m is the weight of the product (g) and E is the extinction coefficient of 3150 at 502 nm. It is expressed in mg/100g of fruit (Alda et al., 2009).

Among the agronomic traits, disease resistance was amid the top priorities for both organic and conventional growers (Hoagland et al., 2015). It can be acquired through breeding techniques and would be a valuable method to manage soil borne as well as foliar diseases and reduce the use of pesticides and insecticides, especially for conventional growers. Plant tolerance/resistance could be assessed by visually identifying the symptoms in the field and recording the number of infected plants along with the degree of infection. Disease severity and spread can also be determined using widely adopted formulas. For the severity: p = n / N x 100 where, p is the disease frequency in the plot (expressed in %), n is the number of infected plants in the plot and N is the total number of plants. While the spread is calculated using $S = \frac{\sum(a \ x \ b)}{n} \ x \ 100$

where, S represents the mean infection intensity (%), $\sum(a\times b)$ is the sum of the multiplication of the number of diseased plants, (a) with the corresponding degree of infection (b) in % and n total number of diseased plants (Ambang, Mengue, Kosma, Asseng, & Dooh, 2016). The less infected the plants are, the more tolerant it is to a certain disease or pest.

Another important attribute is fruit size, measured using a hand caliper, sizing rings or an adjustable sizing band. Consumers prefer medium sized fruits which prompt farmers to target varieties of that size. However, medium and large fruits are more susceptible to physiological disorders and diseases (Parmar, Thakur, Jamwal, & singh, 2018). Resistance to certain diseases comes from the small fruited wild relatives of *S. pimpinellifolium* and *S. lycopersicum* var. *cerasiforme*, which makes it a bit difficult to combine the resistance gene with a larger size (Hoagland et al., 2015).

Other traits that are of lesser importance include color and firmness. Color measurements are taken with a colorimeter while firmness is measured using an Instron firmness tester or penetrometer with a 5mm diameter cylindrical probe (RodrÍGuez-Burruezo, Prohens, RosellÓ, & Nuez, 2005).

D. Breeding methods

1. In organic agriculture

As stated by Dawson, (2007) “With crop cultivars bred in and adapted to the unique conditions inherent in organic systems, organic agriculture will be better able to realize its full potential as a high-yielding alternative to conventional agriculture.” Breeding new varieties under organic farming conditions should be done via organic plant breeding (OPB) methods that aim to fit cultivars into farming systems that rely on renewable organic resources. As a practice, plant breeding is as old as agriculture itself; however, as a scientific discipline, it can be traced more recently to Mendel's experiments in the early 1900s on the inheritance of genetic traits. Plant breeding is a "science-based technology" that aims to deliver improved cultivars to farmers through selection in genetically variable plant populations (Shelton & Tracy, 2016). Despite the huge difference between organic (O) and conventional (C), their breeding goals converge at aiming for higher resource-use efficacy (water, nutrients, light), higher productivity as well as the incorporation of resistance/tolerance to abiotic and biotic factors. Local adaptation may be more important for organic farming as resource recycling and the quality of the inputs that are used can vary from region to region, even though OF practices are highly regulated (Crespo-Herrera & Ortiz, 2015).

When breeding for organic varieties, there are important specific traits that should be included such as weed competitiveness/tolerance, nutrient use efficiency, field resistance and the ability to establish symbiotic relationships with micro-organisms in the soil, which help enhance the uptake of resources and the plant's use efficiency (Lammerts van Bueren et al., 2011); (Zdravkovic, Pavlovic, Girek, Zdravkovic, & Cvikic, 2014). Some traits such as tolerance to abiotic stresses like heat, drought and salinity and host plant resistance against arthropod pests and pathogens, are common for both systems and depend on the geographical area where the breeding is taking place and not dependent on the production system (conventional or organic) or the cultural practices used. Another very important attribute that should be incorporated is the resistance to seed-borne diseases, especially in organic farming where seed treatments are limited.

OPB requires the application of breeding methods that are in line with the organic farming principles and thus is restricted to crossing methods that do not break the reproductive barriers between the species and to selection methods that are based on the evaluation and selection of whole performance. These include intraspecific crossing, backcrossing, mass and individual selection, selection via DNA markers, and hybrid cultivars as long as the next generation is fertile and the hybrid production does not chemically induce sterility (Zdravkovic et al., 2014); (Legzdina & Skrabule, 2005); (E. L. Van Bueren, 2002). While methods that change plants at the DNA level are prohibited from being used in OPB such as genetically modified organisms (Zdravkovic et al., 2014); (Legzdina & Skrabule, 2005); (E. Van Bueren, Struik, Tiemens-Hulscher, & Jacobsen, 2003); (Verhoog, 2007).

Most OPB projects are carried out within practical organic agriculture. Thus, breeding approaches are aimed at the target environment. In order to be able to choose the optimal organic selection environment, it is necessary to gain a much better understanding of the interactions within the entire agricultural biocoenosis, including the actions and interactions of biotic and abiotic stress conditions, soil biota, plant interactions, crop rotation, livestock, and cultivation practices (Horneburg, 2011). Some authors consider that it is essential to carry out the progeny selections under organic environments as it is the only way for the plants to fully express their genetic potential (Singh, HUERTA-ESPINO, & William, 2005). Hence, participatory plant breeding (PPB) and evolutionary breeding (EB), have been proposed as suitable breeding methods for organic farming (Chiffoleau & Desclaux, 2006) (Dawson et al., 2008);(Phillips & Wolfe, 2005), as they ease the selection for local adaptation as well as for specific farmer needs. These methods also help empower farmers as they allow a closer interaction between them and the breeders while giving them greater freedom of choosing germplasm, especially in the case of PPB (Ceccarelli, 2014); (Desclaux, 2005). Participatory breeding is very useful and is used in producing a wider range of improved varieties per breeding cycle because it takes advantage of the GxE interactions by selecting varieties from the environment where they will be used, in order to achieve superior performance and positively contribute to the agrobiodiversity.

Plant breeding exists in three different forms: formal, farmer and participatory (Colley & Dillon, 2004). Formal breeding, known as centralized PPB, is conducted by professional scientists with the goal of releasing new cultivars into the market, taking place on research stations. This form attempts to select and release varieties that are widely adapted through multiple environment testing by trying to minimize the effect of GxE. Additionally, farmers may or may not be involved in the evaluation process, having no real decision-making power. While farmer breeding, also known as decentralized PPB, involves the farmer saving seeds from selected plants in his field that possess desirable qualities and takes place on farmers' fields. This way the essential makeup of the cultivars is maintained through mass population selection. However, despite the gained knowledge acquired by framer inclusions which result in improved varieties, PPB is still met with resistance from institutions because it goes against the traditional structure of public agricultural research. Lastly, participatory breeding, which involves farmers and formally trained breeders, who work together through the various stages of the breeding process. This process includes the collection and conservation of germplasm to eventual distribution of improved varieties that can help in increasing the possibility of farming more lands organically. The process is often situated on the farmer's field and selecting for quality and agronomic traits that are tailored to the farmers' specific needs which he/she knows would greatly improve the variety and make it the most productive (Colley & Dillon, 2004).

PPB projects produce open pollinated varieties. Cross-pollinating OP varieties means that they contain more genetic variability when compared to hybrids, this allows continual adaptations in the varieties in response to human and environmental selections. Not to mention that many organic breeding projects in the public sector incorporate some form of PPB or participatory varietal selection (PVS) due to many organic advocates wanting different models including regionally adapted varieties, a diversity of seed companies, farmer engagement in the breeding process and shared access to genetic resources.

PPB was referred to as "a logical extension of PVS" in which farmers are involved in the earliest stages of selection from segregating populations (Witcombe, Joshi, Joshi, & Sthapit, 1996). The main difference between the two approaches is the stage where farmers are involved, which are the early stages in PPB, ideally in the F2 generation, while a later stage in PVS.

The participatory form of the plant breeding as mentioned before, focuses on identifying specifically the traits that farmers would like to see improved, as well as including them in the whole process from selection to testing. Thus, there are three phases to this program that include identification of needs, selection of the suitable material and finally experimentation (Witcombe et al., 1996). The second phase, evaluating the genetic material, is fundamental to ensure that the attributes are not only being expressed but under low-input organic systems as well (Lammerts van Bueren et al., 2011). This phase also allows the farmers to test the agronomic limitations and eliminate any material that has restricted applicability in organic systems.

Finally, suitable breeding methods for organic are a combination of breeding, variety crosses, bridge and back crosses, temperature treatment, grafting and cutting style, untreated mentor pollen, mass and pedigree selection, indirect selection, ear bed method, test crossing, DNA markers without GMO, hybrids with fertile F1, meristem and tissue culture and generative and vegetative propagation. Hybridization explained by Fentik et al., (2017) can be used, provided that the parents are propagated under organic conditions and the F1 progeny produced is fertile. Another method is cross breeding, which crosses two varieties that are different or related species to produce progeny that has desirable attributes from each. New cultivars are developed to fit different climate conditions, improve taste and/or nutritional value and handle pests and diseases better. After crossing of the parents, the progeny could be used as a new and improved cultivar known as an F1 hybrid or it could be further backcrossed with one of the parents to further increase the derisible traits and decrease the not so desirable ones, however this would take several years and generations. As for DNA marker assisted selection, it can be used if DNA screening is performed without enzymes originating from genetically modified organisms and without radiation.

2. Conventional tomato breeding

It is known that organic and conventional systems differ in a lot of aspects such as cultural practices, thus it would make sense that they would also differ in the breeding techniques used. Breeding goals of tomatoes have gone through four phases through the years, with breeding for yield in the 70s, shelf life in the 80s, taste in the 90s and nutritional quality presently (Acquaah, 2009). As well as increasing yield, improving fruit quality, hybrid vigor and resistance to biotic and abiotic stresses.

The different methods include Cross breeding, Anther culture aided tomato breeding, Molecular Marker Technology, Mutation breeding and Genetic engineering to develop GMOs. Anther culture aided tomato breeding, it is a faster way than crossing to achieve improved varieties by taking a homozygous line of tomatoes from the anther of an F1 generation. The variety obtained is called a double haploid and can be further assessed in target environments for preferred traits. It is essentially the regeneration of a whole plant from the anther (male organ of the plant) (Davis, Joshi, & Panthee, 2011).

Molecular marker technology (particularly DNA) is an efficient and effective tool that generates reliable information that can be used at any stage of the crop breeding (Moose & Mumm, 2008), unlike usual breeding that depends on phenotypic markers such as fruit color and leaf shape, that require a grown plant. As for mutation breeding, it involves the use of mutagens either physical like X-rays and UV-rays or chemical such as bromine and ethidium bromide to cause changes in varieties. They can be used to create traits that can be inherited from the parent to offspring. Lastly, there is genetic engineering which alters the genotype of a crop in a way that does not occur naturally. The most common form is inserting a new trait from one species into another such as virus gene in sweet pepper or bacterial genes in corn. Organisms developed under this technology are known as GMOs while in agriculture, crops are known as transgenic plants. However, this particular method has had a lot of controversy surrounding it especially when it came to food and food safety. As well as its effect on natural ecosystems, gene flow into non-genetically modified crops etc. Regardless, transgenic plants have been engineered to possess tolerance to herbicides as well as become resistant to insects and viruses (Davis, Joshi, & Panthee, 2011).

It is important to evaluate these new cultivars in variety trials to assess the performance and expression of the trait(s) bred for as well as its overall performance and fruit quality.

E. Conventional tomato variety trials

Tomato cultivars have been evaluated under conventional management practices, however most of these trials included a parallel organic experiment to be able to compare their performance. The focus in this paragraph will be on the conventional portion of the trials. Zhao et al, (2007) set a study on a site that had been in conventional drip-irrigated plasti-culture tomato production research for five seasons before the experiment took place at the University of Arkansas at Monticello. A total of six cultivars including Cherokee Purple and Kentucky Beefsteak were evaluated for total weight, total number, average weight and percent marketable fruit, and total weight of culled fruit. There were significant year effects on marketable fruit yield, total number of marketable fruit and total weight of culled fruit, but no year effects were observed for average weight of marketable fruit or percent marketable fruit or system and system interactions in the overall analysis of variance. However, there were cultivar effects on all yield attributes measured. A year x cultivar effect occurred for total number of marketable fruits and total weight of culled fruits. However, only the results of the total and percent marketable yield were compared between the varieties, while the other results were averaged with the organic results. In the first year of the experiment, Arkansas had the highest total marketable yield with 63% while Kentucky was the lowest with 36%. While in the 2^{nd} year, the yield in general was lower for all the cultivars due to unfavored weather and too much rainfall; Kentucky still had the lowest marketable yield while Cherokee Purple had the highest percentage. After two seasons of inorganic granular fertilizer application, the exchangeable K levels were high and soil pH more acidic (Zhao, Chambers, Matta, Loughin, & Carey, 2007).

Riahi et al, (2009) carried out a trial at Mannouba support research station in northern Tunisia, assessing four cultivars. One OP called Rio Grande and three hybrids Firenze, Hypeel 108 and Perfectpeel. The cultivars studied are frequently used by Tunisian growers because of their adaptability to local conditions, good yield potential, disease resistance and fruit quality. The parameters measured encompassed marketable yield, Brix, pH and titratable acidity, firmness, lycopene and total phenolic content. The results showed that marketable yields were not significantly different among cultivars with the average yield being 55.62 t/ha. As for lycopene content, the values varied from 1.05 mg/g dry weight in Perfectpeel to 1.38 mg/g dry weight DW in Rio Grande. These values fall within the ranges found in studies by Riahi, (2009) (0.51–1.25 g/Kg DW) and Pieper, (2009) (1018–1641 µg/g DW) for conventional field tomatoes. While average phenolic values ranged from 6.62 mg gallic acid equivalent/g DW in Firenze to 8.16 mg gallic acid equivalent/g DW in Hypeel 108 and were comparable to those found by Zhou, (2006) in conventional tomatoes.

Edlin (2009) conducted a trial at the Western Kentucky University Research Farm evaluating three cultivars, a commercial hybrid Crista, a dark beefsteak type heirloom Cherokee Purple and a yellow heirloom Mr. Stipey. The plants were irrigated using drip tape, covered by plastic mulch to provide water and fertilizers. As for the parameters, data was collected on the number of fruits per plant and individual fruit weight, size and grade. The results show that the variety Crista produced significantly higher quality fruits than Cherokee Purple and Mr. Stipey. While Cherokee Purple produced significantly heavier fruit than the other two cultivars but had fruits of similar size to Crista. Finally, Mr. Stipey produced significantly more fruits per plant than either of the other two cultivars. It is useful to add that Crista was developed under and for conventional farming and its practices thus would be expected to optimally perform under this system. However, the other cultivars did not produce significantly better grades under the conventional setting, likely since they are heirloom varieties that are bred for organic farming systems and are not used to the cultural practices being used.

F. Examples of organic tomato variety trials

There have been several attempts at tomato variety trials around the world in organic as well as conventional farming systems. The following are a few brief examples representative of organic variety trials in different climates and regions.

Boyhan et al., (2014) undertook a trial in Georgia to compare fresh market modern F1 varieties commonly grown in the southeastern United States with open-pollinated varieties popular among organic growers. 19 beefsteak type cultivars, in Georgia, including Abraham Lincoln, Celebrity, Cherokee Purple, Florida Pink, Mountain Fresh Plus, Ozark Pink and Scarlet Red were assessed for early total marketable yield, total marketable yield, number of fruits and average fruit weight. As for the results, there was no variety x year interaction for early total yield and total marketable yield. Cultivar HSX 8115H had the highest yield for total early fruit with 18,804 lb/acre (21.08 tons/ha). ‘Mortgage Lifter VFN’ and ‘Florida Pink’ had significantly lower total early yields compared with 14 of the varieties in the trial. Two open-pollinated varieties that had reasonably good total yield included Costoluto Fiorentino and Neptune with 22,046 (24.71 tons/ha) and 15,436 lb/acre (17.3 tons/ha), respectively but were significantly lower than the top five yielding varieties. Fruit size averaged 5.8 oz compared with beefsteak tomato fruit, which are in the 6 to 10-oz size (Boyhan, Tate, McNeill, & McConnaughey, 2014). However, there were a few exceptions like Cherokee Purple had the second highest average fruit size of 8.4 oz. BHN 602 had the highest total yield in both years of the experiment. Trial entries were also evaluated by variety type and by growth habit. There was a significant variety type x year interaction with F1 hybrids having out-yielded open-pollinated varieties in both years by 5,825 lb/acre (6.53 tons/ha) and 16,893 lb/acres (18.94 tons/ha), respectively. There were also significant differences between growth habit. Determinate varieties, Celebrity and BHN 602, yielded better with 26,846 lb/acre (30.09 tons/ha) compared with indeterminate or semi-determinate varieties. Early yields were dominated by F1 hybrids such as BHN 602 with 8,197 lb/acre (9.19 tons/ha). In conclusion, the F1 hybrid varieties did better than the open-pollinated varieties, which is not surprising since F1 hybrids often exhibit hybrid vigor and had more uniform fruit.

Parmer et al, (2018) evaluated the yield performance as well as other agronomic characteristics of 12 cultivars, five open-pollinated (called varieties in this trial) such as Roma, Sioux and seven hybrids including Yash and Naveen 2000 in Himachal Pradesh, India. Parameters assessed included growth parameters such as days to harvest and plant height, fruit characters such as number of fruits per plant and fruit size, fruit quality such as total soluble solids, acidity, ascorbic acid, carotene and lycopene and finally yield components such as fruit yield. Analysis of the results showed significant difference between the OP and hybrid varieties for days to maturity. The hybrid varieties took fewer number of days from transplanting till the first harvest than the OP varieties, with a minimum of 67 days and a maximum of 72 days. While the OP cultivars took between 69- 74 days (Parmar et al., 2018). Other studies (Naz, Haq, Asghar, Shah, & Rahman, 2011) showed that the time taken from transplanting to first harvest for the tomato cultivars ranged between 70 and 120 days. Next parameter measured was the number of fruits per plant in which the hybrid Red Gold recorded the highest number of 26 fruits per plant while two OP and 2 hybrids bore the lowest number of fruits. The highest total soluble solids (TSS) was recorded in hybrids Manisha, RK 123, Yash, Red Gold and Naveen 2000 and OP Best of all and varied from 4.79% to 6.02% (Parmar et al., 2018). As for the acidity of the fruits, all the hybrids had high but statistically similar acidity ranging from 0.54-0.58 g/100 ml of juice, while the OP varieties recorded lower values during the three years of the study. The hybrid varieties recorded higher ascorbic acid (18.53-22.08 g/100 ml of juice) compared to the open-pollinated ones (11.53- 14.52 g/100 ml of juice). The variety Best of all recorded maximum carotene content (9.51 mg/100 g of fruit) and lowest was in Manisha hybrid (5.25 mg/100 g of fruit). Data corresponds to earlier study by Gupta (2011), who reported β-carotene content range from 4.80 to 5.30 and 5.40 and 6.78 mg per 100 g in different tomato genotypes. The highest lycopene content was observed in the OP Best of all and the lowest found in the hybrid Naveen 2000. Data corresponds to earlier study by Gupta (2011) who reported lycopene content range from 1.40 to 4.15 and 3.23 to 4.03 mg per 100 g in different genotypes of tomato. Finally discussing fruit yield, the results demonstrated that Red Gold hybrid produced the maximum tomato fruits (14.33 tons/ha) and the lowest yield reported for Best of all (3.37 tons/ha) and Marglobe (3.47 tons/ha).

Nine varieties were assessed in another experiment by Toledo et al, (2011) which took place in Montes Claros, Minas Gerais, Brazil. The purpose of the study was to evaluate yield and quality of tomato fruits in the summer under an organic production system. Four of the cultivars were OP including Chadwick Cherry, Pitanga Vernelha, Santa Clara and Santa Cruz Kada and five hybrids including Marguerita, Nicholas, Ellen, Majesty and Ruler. The parameters evaluated in this trial included the average of racemes, total yield, marketable yield, rate of marketable yield, rate of fruits identified according to the type of damage and rate of fruits in each size class. Significant differences were observed for all the traits of the varieties. Chadwick Cherry and Petagna Vermelha produced a high number of racemes and fruits however with lower average fruit weight (Toledo et al., 2011). In this trial, the production of traditional (OP) cultivars such as Santa Clara and Santa Cruz showed no significant differences in the total number of fruits produced but showed difference in the production of marketable fruits. The average marketable yield of the cultivars ranged from 12.3 t/ ha to 23.9 t/ha and the hybrid Marguerita presented the highest yield, which was related to a high productivity associated to a lower fruit loss due to injuries of pests and diseases in comparison to the other hybrids. The average marketable yield of cultivars was close to that obtained by other authors. Zuba (2007) also studied the cultivar Santa Clara and obtained marketable yield of 19.3 t/ha with organic fertilization. The cultivar Chadwick Cherry presented the highest proportion of marketable fruits followed by the cultivar Pitanga Vermelha. Both varieties known as “heirloom”, or traditional cultivars used in organic for their rusticity and adaptability to climates ranging from extreme cold to hot. The common cultivars and the hybrids produced a lower proportion of marketable fruits due to the attack of pests and pathogens and the production of unmarketable fruits. Approximately 50% of the production of the other cultivars were composed of damaged fruits by injury or pests and diseases, or fruits out of the commercial standard. All cultivars except Chadwick Cherry and Pitanga Vermelha presented high percentage of fruit loss due to unmarketable fruit size, confirming that the organic tomato does not fit the quality standard for the conventional tomato (Toledo et al., 2011). Chadwick Cherry and Pitanaga Vermelha reached yield similar to that of most evaluated cultivars with better quality fruits.

Brady, (2011) assessed a trial that took place in southeastern Puerto Rico to evaluate the yield and quality performance of 14 varieties, 11 OP including Ace 55, Eva Purple Ball, Flora Dade, Homestead, Marion, Neptune, Ozark Pink, Roma, Super Sioux, Traveler 76 and Tropic. Three hybrids that included BHN 444, Celebrity and Early Girl. The parameters assessed included weight of marketable fruit per plant, percentage of unmarketable fruit by weight, number of marketable fruits per plant, marketable yield, as well as tomato quality attributes through brix, fruit weight and consumer preference evaluations. Significant differences were found among the cultivars for weight of marketable fruits per plant, percentage of culled fruit by weight, number of marketable fruits per plant, marketable yield and average weight per fruit. On average, the top performing cultivars in the two-year trial for marketable fruit weight per plant included Roma, BHN 444, Neptune, and Early Girl. Marion and Super Sioux were among the cultivars with the lowest fruit weight per plant. The OP cultivars Roma, Ozark Pink and Traveler 76 had the least amount of culled fruit, while the hybrid cultivars Marion, Super Sioux, Tropic, and Ace 55 had more than 50% culled fruit. The culling was mainly due to radial fruit cracking and caterpillar damage. As for the number of marketable fruits per plant, Roma, and Early Girl were among the cultivars which produced the greatest number of marketable fruits per plant. Marion, Ace 55, Tropic and Super Sioux were among the cultivars which had the smallest number of fruits per plant. The hybrid cultivar BHN 444 had the greatest marketable yield in both years whereas the OP Marion had the lowest marketable yield. Evaluations of the cultivars were also made through consumer preference tests where the taste and overall appearance of the fruits were tested by a panel of volunteers. In both years, OP Ace 55 and hybrid Early Girl were among the cultivars that were judged to have better tasting fruit with the average taste test scores ranging from 4.4 for Ace 55 to 2.8 for BNH 444. While Early Girl and Super Sioux were among the cultivars which received a higher taste score during the second year of the trial. As for overall better appearance, Early Girl, Neptune and Traveler 76 were ranked the highest. Moving on to brix, the OP varieties along with the hybrid Early Girl had among the highest brix ratings with the average value being 4.3 and 4.5 for both years. The average brix of 4.3 is the same as that reported by Palada, (2001) for 12 hybrid tomato cultivars grown under organic management in the U.S Virgin Islands. Finally, for the average fruit weight per plant, BHN 444 and Ace 55 were among the cultivars that produced fruit of greater weight while Roma and Early Girl were among the varieties that produced fruits of less weight.

Sidhu and Nandwani, (2017) evaluated a trial that took place on a farm in Nashville, Tennessee to evaluate the yield performance and other agronomic characteristics of tomato cultivars grown over a two-year period. A total of 26 cultivars were evaluated including Bing Cherry, Black Cherry, Black Prince, Cherry Sweetie, German Johnson, Mortgage Lifter, Moskovich, Hillbilly, Mountain Prince, Northern Delight, Oregon Spring, Principe Borghese, Rutgers VF, Sweet Tomato, Tang Tomato, Storage, Arbason F1, Glacier, Gold Nugget, Siletz, Roma, Cherokee Green (bicolor beefsteak), Pink Brandywine, Brandywine, Pink Bumblebee and Indigo Rose. Data was collected on total yield, marketable yield, fruit weight, number of total, marketable and unmarketable fruits. Marketable yield ranged from 3.10 tons/ha to 27.25 ton/ha with ‘Arbason F1’ yielding the highest and ‘Hillbilly’ yielding the lowest. Arbason F1’, ‘Roma’ and ‘Gold Nugget’ performed well. As for the unmarketable yield, it ranged from 1.80 to 57% with ‘Pink Bumblebee’ having the lowest culled fruit and ‘Mountain Prince’ having the highest culled fruit (Sidhu & Nandwani, 2017).

CHAPTER III

MATERIALS AND METHODS

A. Surveys on tomato traits preferred by growers and consumers

In order to set objectives for the variety trial, two types of surveys were created, one for organic tomato consumers and one for organic tomato producers. The producer survey (Appendix II) was designed to help better understand the problems faced by each producer as well as the most desired traits they are looking for. While the consumer survey (Appendix II) helped give an idea of what is important to the consumer when buying organic tomatoes as well as any issues they might have. Approval for the surveys to be used was obtained from the Institutional Review Board at AUB before they were filled in. The surveys were filled in prior to the experiment and were designed to include a few yes/no questions with an option to elaborate, as well as open ended questions. The surveys were filled in the organic farmers market "Souk el Tayeb" where about 30 consumers and 6 farmers were surveyed.

B. Experimental site

The variety trial was conducted at Adonis Valley, a certified organic farm at Fatre, Lebanon. The farm is located at 34.085N, 35.72028E and altitude of 596m (mean elevation from sea level). The weather is Mediterranean with average annual rainfall of 1000-1100 mm. The area used for the experiment had been previously planted with kale and broccoli. The soil was of a silty loam texture, as determined after gathering samples and performing "Soil Texture Analysis". The total experimental plot covered an area of

63.36m^2 (17.6m long x 3.6m wide) divided into 5 rows with 40cm between transplants and 60cm between the rows. Each variety had a total of 36 plants divided into 3 replicates, with 12 plants per row. Onion and basil were planted in between each replicate as a border (fig. 4).

C. Experimental design and treatments

The experiment was conducted from May till September 2018, with the seedlings transplanted on May 11th. It was conducted on five indeterminate open-pollinated tomato varieties including three lines from a local breeding program at the American University of Beirut AUB1, AUB2, AUB3, and two other varieties sold for organic management, Indigo rose and Cherokee purple. On June 1st, the plants were supported by bamboo stakes and then each group of four plants were tied together in the shape of a teepee for physical support (fig 6).

1. Varieties assessed in this study

a. Commercially imported varieties

Indigo Rose's origin began in the 1960s by two breeders who cross cultivated tomatoes with wild species from Chile and the Galapagos Islands. It was then bred and released in 2012 at a program at the Oregon State University and was developed as the first variety to have anthocyanins in its fruits unlike all other "domesticated" cultivars who only have anthocyanins in their stems and leaves (Oregon State University, 2012). Anthocyanin is produced when the fruit is exposed to sunlight, with its characteristic purple color also developing. The color changes from a purple blue to a dull purple-brown when ready to be harvested. The flavor is a good balance of sugars and acids. Lastly, it a full season cultivar with an average first ripe date of 91 days.

Cherokee Purple is a variety that is dated to pre 1980s and is recognized as an old Cherokee Indian heirloom that originated from Tennessee (Boyhan et al., 2014). It was named by Craig LeHoullier in 1990 after he received a packet of seeds in the mail with a note from John Green from Tennessee, stating that the seeds were originally received from Cherokee Indians. This variety is a dark beefsteak type tomato with a characteristic dusky red pink purple color with a green shoulder. Being an heirloom variety, it is susceptible to growth cracks, has a good balance of sweet, acid and savory flavors and needs about 72 days till it reaches its first ripe fruit.

b. Locally bred lines

As for the AUB lines, the AUB1 variety originated from a cross between local Baladi type with *Solanum habrochaites* then the progeny was backcrossed to the Lebanese baladi and screening over 8-10 generations for resistance to *Tomato yellow leaf curl virus* and to produce high yield. Resistance is conferred by unknown gene(s), (other than TY1, TY2, TY3 and TY5). While AUB2 and AUB3, also originated from a cross between local Baladi type but with another *Solanum habrochaites* accession with the resistance genes TY1/TY3, then the progeny was backcrossed to the Lebanese Baladi and screening for over 8-10 generations for resistance to *Tomato yellow leaf curl virus* and for high yield.

Figure 4. The experimental design of the variety trial

D. Climatic measurements

Temperature and relative humidity were recorded using a HOBO Pro V2 data logger, Onset,USA, protected by a radiation shield from rain, sprays and direct solar radiation. It was hung in the field on a metal pole about 1.5m from the ground, making sure that it was exposed and above the canopy level of plants (fig 5). It was installed on the 26th of June and removed on the 6th of September after the termination of the trial. Temperature and RH were recorded every hour in a 24-hour interval using sensors.

Figure 5. Data logger protected by a radiation shield

Figure 6. Transplants supported by bamboo stakes in the form of a teepee

E. Agriculture practices

The conventional cultural practices were performed on all the seedlings. The field was prepared before the seedlings were transplanted by spreading compost and ploughing. Chicken manure compost was prepared on the farm and sprayed at a rate of 10 ton/ha and incorporated using a local plow pulled by a bull. This was followed by preparation of the beds. Seedlings were transplanted on May 11th by hand with a spacing of 40cm between seedlings. For fertilization, Fertiplus (4-3-3 chicken manure) was applied manually at a rate of 1 -1.5 t/ha, on May 30th. The second fertilizer application was GREENLIFE, an organic liquid fertilizer, applied to the soil at a rate of

1/100 dilution factor on July 20th. The seedlings were hilled and supported by bamboo stakes, with each set of four seedlings grouped together in a teepee form for extra physical support. Hand pruning was done a few times during the season to remove suckers, lower shoots as well as any infected leaves. Irrigation was applied using 4 l/hr in-line emitters, spaced at 40 cm, every other day for 30 mins from May 11th till June 1st, followed by water deprivation for 12 days in order to encourage flowering (stage 6); then was increased to 45 mins at fruit set (stage 7) in order to reduce blossom end rot incidence of the fruits.

F. Phenological development

Phenology assessment was conducted based on phenological growth stages and BBCH-identification keys of solanaceous fruits. It was carried out from June 29th till September 6th twice a week. Two pre-determined plants were chosen from each row, thus six plants for each variety have been observed. First, the total number of side shoots was counted, followed by the total number of fruit clusters and the total number of open flowers. Since the plants were transplanted as seedlings, the first principle growth stage 0: germination was skipped. The date each variety reached each stage was recorded. The days to maturity of each variety was also calculated for each variety as the time it takes from transplanting till the 1st mature ripe fruit.

Figure 7. Sticky traps hung in the field

Figure 8. *Tuta absoluta* pheromone trap

G. Pest monitoring

On May 29th when the plants were at the 2nd stage of development (formation of side shoots), blue and yellow sticky traps were hung in the field, to attract and capture whiteflies, aphids and thrips and were replaced by new ones on June 15th (fig 7). A *Tuta absoluta* pheromone trap was hung about 150m away from the field, using 2 pheromone capsules (*Tuta absoluta* lure) and was changed 4 times during the season (fig 8). The adults were counted before changing the capsules each time.

Scouting of the leaves began when the seedlings reached stage two of development (formation of side shoots) on May 29th and was carried out at weekly intervals till they reached the 8th stage of development (ripening of fruit and seed) by August 6th. It was carried out on two pre-determined plants in each row thus six plants for each variety. The procedure for monitoring the damage of South American tomato pinworm (*Tuta absoluta*) and pea leafminer (*Liriomyza huidobrensis*) on the leaves began by randomly selecting a lower, middle and upper shoot on the designated plant. After selecting the shoot, the total number of leaves was counted, followed by inspection of the lower and upper sides of each leaf and counting the leaves with damage in the form of galleries. As for the presence/absence of rosy (*Dysaphis plantaginea*), green (*Aphis pomi*) and black (*Aphis fabae*) aphids, and whiteflies, (*Bemisia tabaci*) the same procedure was carried out in picking a lower, middle and upper shoot and then counting the number of leaves and noting the number of pests if present. The scouting was carried out using a 10x lens (Sight Savers, Bausch & Lomb, USA). Finally, for the scouting of early blight (*Alternaria solani*) infection, initial symptoms were noticed on the variety Indigo on July 23rd, black lesions were found on the leaves that were distinct to the disease followed by the yellowing of the whole leaf.

The infection then spread to the stem causing brown lesions as well which eventually caused death of the plant. The infection spread to neighboring varieties and ultimately other blocks.

Scouting and monitoring of pests and diseases was the first step in control measures in order to determine if spraying was needed, it was done according to a spraying calendar based on integrated pest management and using natural pesticides products allowed in organic production that included neem oil (azadirachtin) which was sprayed 5 times during the season as an insecticide, Bt (*Bacillus thuringiensis*) which was sprayed twice and Spinosad which was sprayed twice throughout the season as well.

H. Scouting for physiological disorders and fruit pest damage

Scouting of the fruits began on July 11th when the plants reached the 8th stage of development (ripening of fruit and seed) and ended on September 6th upon senescence of the plants at stage 9, once a week at each harvest. All harvested fruits were inspected for various pests, diseases and physiological disorders. The disorders included blossom end rot, growth cracking, zippering, cat-facing, sunscald, among others (fig 9). These were encountered at different intensities depending on each variety. Caterpillars were a major pest that left the fruits damaged as well as damage caused by chickens found on the farm. The assessment was carried out by inspecting the fruit for the abovementioned problems and then separating them into marketable and unmarketable fruits.

Zippering

Growth Cracking

Chicken

Blossom end rot

Figure 9. Physiological disorders/damages of the fruits

I. Yield

Fruits were harvested from July 11th till September 6th, twice per week. Harvest took place early in the morning when the fruits were still cool. Only the fruits at the breaker and ripe stages (according to Guide to Ripening stages of tomatoes; California Tomato Commission) were harvested, depending on the demand of the farmer that day. The fruits were picked by grasping firmly but gently and pulling upwards with the thumb and forefinger pressed against the stem. Not all the plants were harvested every time, only the ones that had fruits at the desired stage. This was done by picking the fruits from the plant, separating them (into marketable and unmarketable) and then counting and weighing (done using a digital balance). The number of harvests for each variety was recorded along with the date of the first and last harvests.

J. Fruit quality at harvest and post storage

Postharvest tests took place on August 14th at peak harvest. Twenty-two fruits were harvested from each of the three varieties (AUB1, AUB2, and Indigo), thirteen for Cherokee and fourteen for AUB2 in order to assess quality of the tomato fruits at harvest. Each variety was harvested at the ripe stage taking into consideration the assessment of fruit color (with respect to each variety) and fruit firmness. Tomatoes were picked from all the varieties on the same day, packed in labeled boxes and transported to the American University of Beirut, FAFS, Agriculture Department, research lab where they were subjected to post harvest analysis. First the weight and size of each tomato was measured using a digital balance and a caliper respectively. Tomatoes were subjected to grading based on official Lebanese Libnor standards, No. 476: 2012 for tomatoes, depending on the typical size and color of each variety as well as physical imperfections. The grading was divided into 3 classes: Extra, Grade 1 & Grade 2. Fruits that were typical to the variety in size, color, growth and were void of physical imperfections were considered grade “Extra”. While fruits in Grade 1, were allowed minimum imperfections in terms of shape, growth and color as well as cracks up to 1 cm in length. Finally, fruits classified as Grade 2 were all fruits rejected from the other two grades and were allowed to have imperfections in terms of shape, growth and color and cracks up to 3cms in length. Next the skin color of each fruit was measured using a colorimeter (Agrocolor; Agrosta SARL, France) on 2 opposite sides. The RGB data from the colorimeter were translated into hue via RGB Color Wheel of colorspire (www.colorspire.com). Since the skin of the Indigo tomato has both a red and violet color, the readings were taken for each color separately. While the color for the Cherokee variety could not be taken accurately due to the heterogeneity of the skin color. The hue angle was then entered into a color website (www.color-blindness.com/color-name-hue) in order to find the color name of each variety. In order to measure flesh firmness, the skin was peeled off on opposite sides of each fruit. A penetrometer (mod. FT 327 (3-27lbs), Italy) fitted with a 4mm tip was used to measure the maximum force (lb) needed to penetrate the peeled skin. Drops of juice that came out from the fruit after the firmness test were used to measure the sugar content which was quantified using a digital hand-held pocket refractometer (PAL, Atago Co, Japan) calculating the juice degrees brix. Ten tomatoes from each variety were used to measure the titratable acidity. The fruits were placed through a juice extractor (MK-6115, Muller Koch, Germany). The diluted extracted juice was titrated to an end point of pH 8.1 with 0.1N NaOH using the auto-titrator formed of pH Module 867, the dosing unit Dossino 800 and Tiamo software (Metrohm, Switzerland). Calculating the tomatoes acidity was performed using the equation: A= V×0.1N×0.064 where A is the acid concentration in g/L, V is the NaOH volume spent in the titration, N is the normality of NaOH, 0.064 is the factor to express the citric acid acidity in meq.

The same abovementioned procedures were done on ten mature ripe fruits harvested all on the same day, at the full ripe stage for each variety (according to Guide to Ripening stages of tomatoes) to evaluate storage and shelf life. Storage was done in order to evaluate its effect on the external and internal quality of the fruits. It was done to assess the shelf life of each variety in the fridge over a certain period of time equivalent to household storage by consumers. Pre-storage non-invasive activities were performed before placing the tomatoes in the fridge at 4^oC. These included weight, size, color, grading and damage assessment which were used as fruit quality characteristics at harvest, as well as firmness and brix which were measured on the final day as they are considered invasive procedures. Average percent weight and size losses were calculated for each of the 10 fruits for each variety based on the following formula: % loss = [(D1-D3)/D1]*100. Where D_1 is the weight of the fruit on the initial day before storage and D3 is the weight of the fruit on the final day after storage.

K. Lycopene content

Lycopene extraction was performed in order to assess the lycopene content in each variety. The procedure began by washing, cutting and placing the fruits in an extractor (Braun, Germany) in order to ensure a homogenous mixture. The contents were then placed in labeled beakers with each variety name. Test tubes were weighed, the balance zeroed and 0.6ml of the extract were taken from each sample using a pipette. Triplicates were made for each variety. A BHT (butylated hydroxytoluene used to prevent oxidation) solution was prepared by taking 0.25 g of BHT powder and mixing it with 50ml of acetone (100%). 5ml of BHT were then mixed with 5ml of ethanol (99%) and 10ml of Hexane, this solution was placed in a separate test tube and shaken. The extracted tomato juice sample was then added, the test tube shaken again and then covered with tin foil to prevent further oxidation. After all the tubes were prepared the same way, they were placed in ice, in order to prevent any reactions from taking place, and placed on a shaker for 15 mins at 180 rpm. When the time was up, 3ml of de-ionized water were added to each test tube and placed on the shaker again for 5 mins. The tubes were then removed from the ice, left to reach room temperature and separate into layers; the top layer being an organic layer + lycopene complex while the bottom layer is water. In the meantime, cuvettes were rinsed with hexane before filling each up with extract from the top layer of the sample. The blank is filled with hexane and placed in the spectrophotometer and the program Visionpro was launched. The wavelength was adjusted to 503nm. The cuvette should be defined as either in use or blank, the program then calibrated and launched.

L. Sensory evaluation

Sensory evaluation was based on a taste test done by 30 semi-trained participants divided between 16 females with an age range of 28 to 51, 14 males with an age range of 32 to 56 and a culinary chef. They are considered connoisseurs who are always sought after when assessing new varieties of tomatoes. The participants evaluated the five different varieties and filled in a survey respectively. The evaluation was carried out to test the appearance and taste of the fruits, consumer’s willingness to buy the variety as well as a description of attributes. This was done using a detailed survey based on a 7- point hedonic scale (Appendix III).

Before the sensory evaluation began, trays were prepared for each variety with a plate containing 2-3 tomato pieces for tasting, a cup of water, a cup for expectoration, a cup of crackers, a napkin and the survey. After that, covered bowls were placed on the table and the respective trays in front of them. In order to avoid the samples being presented in the same sequence for more than one panelist, they were randomized, and each panelist got a specific order of the varieties along with a survey for each cultivar. The person sat down and began with the first variety, tasting the pieces and looking at the fruit as a whole (presented in the bowl); the respective survey was filled in. An agro-touristic chef specialized in creating menus from organic tomatoes was asked to look at and taste each variety and fill in two sheets: one related to the unique characteristics for each and the other related to the presence of flavor and appearance characteristics based on a scale.

M. Cost

Production costs of the inputs, labor and transportation were collected from the farmer throughout the season.

N. Statistical analysis

Statistical analysis of the data was performed using SPPS version 25 (IBM corp, Armonk, IL, USA). The data were assessed for normal distribution using Shapiro-Wilk test. If the assumptions for normality were not respected, non-parametric tests were used including chi-square and Kruskall- Wallis. According to Shapiro-Wilk, all the data were normally distributed for % infection of leafminer, total number of ripe fruits, total, marketable and unmarketable yield, number of shoots, clusters, flowers and physiological disorder parameters. They were tested using two-way analysis of variance followed by Tukey test, which was used when multiple comparisons were needed in particular to compare averages between the replicates. The standard error was calculated. Means were separated using Fisher's protected LSD (least significant differences) at a 5% significant level. This was done to determine the effect of the variety and the block. Grading was analyzed using non-parametric chi square. Weight, size, firmness, degrees brix and titratable acidity were tested using one-way analysis of variance followed by Tukey test due to only having one fixed factor which was the variety.

The consumer and farmer surveys were not subjected to statistical analysis, instead the most important data related to the results presented in this thesis were added in the form of tables and explained descriptively.

While the sensory evaluation consisted of three parts, the general look and taste as well as interest in buying of the semi-trained consumers were subjected to statistical analysis similar to the abovementioned parameters including weight and size. The likes/dislikes of the consumers for each variety were placed in frequency bar graphs as well as spider plots (to compare between the local AUB lines and commercially imported varieties). Lastly, the chef provided flavor, appearance and texture attributes for each variety that were placed in separate tables as well as culinary uses for each.

CHAPTER IV

RESULTS

A. Surveys on tomato traits preferences for growers and consumers

Tomato trait surveys for growers and farmers were filled in prior to the experiment to understand the needs, concerns and problems faced by both when growing (table 2) and purchasing organic tomatoes. The most important results are highlighted below:

Around 73% of consumers would be willing to buy new varieties while 26.70% were only somewhat willing. As for tolerating default in organic tomatoes, 76.70% of the consumers would tolerate default in the shape, color, firmness and cracks while 23.30% would not.

Consumers chose to buy organic tomatoes instead of conventional for many reasons such as being healthier and containing less pesticide residues (table 1). They would be willing to try new varieties out of curiosity and better price among others. As for the producers, they look for specific traits when choosing to grow organic tomatoes such as resistance to pests and diseases as well as newness of the variety (table 3).

Table 1. Characteristics preferred in purchasing organic over conventional

Reasons for buying organic tomatoes:	Characteristics looked for when buying organic tomato:	Consumers would be willing to try new varieties based on the following:	Consumers would like to see the following improved:
Healthier More environmentally friendly in terms of production practices Better quality & presentation Better flavor Less pesticide residues	Better taste No pesticide residue Long shelf life Nutritional value Color Size Shape Firmness Origin	Curiosity Attractive display Price Taste Uniqueness Advantages of the variety	Price Longer shelf life More accessibility Flavor Better firmness

Table 2. Problems related to growing tomato under organic management – Answers from the producers

Problems related to varieties adopted to organic management are essentially:	The most important problems/aspects farmers would like to improve in varieties for organic management:
Sanitary aspect Adequacy of yield and taste Varieties adapted to the length of season in the region	Resistance to pests and diseases Wider range of organic pesticides & fungicides for pest/disease management More market options to sell organic

Four farmers carried out tests on their farms to assess vegetables like lettuce however only one for tomato varieties, all would be interested in participating in variety trials on their farms in the future.

Table 3. Important parameters looked for by producers when choosing organic tomato

When choosing seeds & varieties, importance is given to:
Resistance to arthropod pests
Resistance to diseases & viruses
Yield
Organically certified seeds
Newness of variety
Adapted to climate & region

B. Climatic measurements

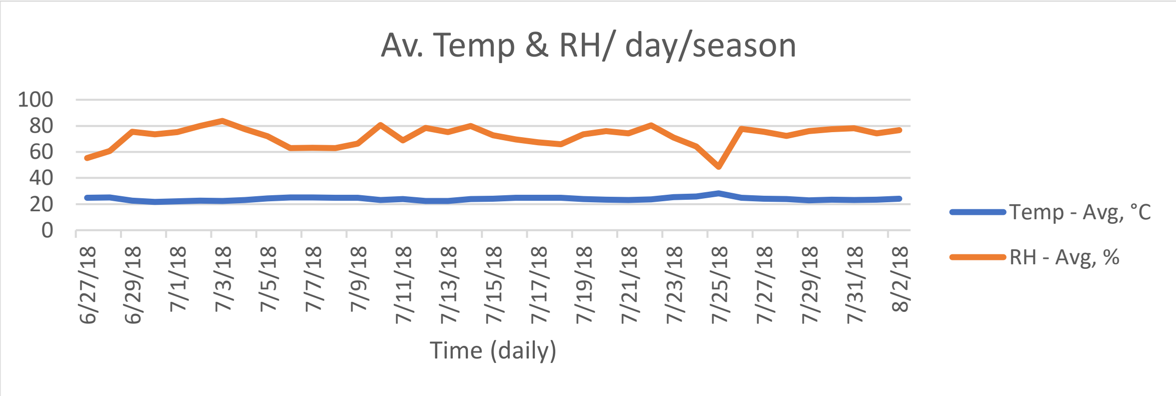


Figure 10. Average temperature and relative humidity recorded daily from June till August

The temperature and relative humidity were recorded daily from June till August via a data logger. The maximum temperature recorded was 33.67°C with the lowest being 17.63°C. As for %RH, the highest was recorded at 92.72% and the lowest at 32.12% which falls within the range of a Mediterranean climate with an elevation of 500m facing the sea (fig. 10).

C. Variety Profile

The varieties assessed in this trial are indeterminate and open-pollinated. AUB2 is a beefsteak type late variety tomato that was low yielding, had large sized fruit and was susceptible to growth cracks. AUB1 and AUB3 are also beefsteak type tomatoes, medium yielding with average sized fruits and typical red color (table 4). Indigo is a cherry type fruit with high yields but small sized fruit and a distinct violet color. Finally, Cherokee is an heirloom tomato, also beefsteak that produced low yields of medium sized fruit that were susceptible to BER and had a distinct purplish brown color as well (Appendix I).

Table 4. Hue angle and color name of each variety during storage

	AUB2		
	Day	Hue angle	Color Name; Hue
	D0	7	Scarlet; red
	D6	5	Scarlet; red
	D8	5	Scarlet; red
	AUB3		
	Day	Hue angle	Color Name; Hue
	D0	5.5	Scarlet; red
	D6	5	Scarlet; red
	D8	5.25	Scarlet; red
	AUB1		
	Day	Hue angle	Color Name; Hue
	D0	179	Aqua; blue
	D6	179	Aqua; blue
	D8	3	Red; red
	Indigo Rose		
	Day	Hue angle	Color Name; Hue
	D0	9.5	Scarlet; red
	D6	9	scarlet; red
	D8	15	Orange red; orange
	Cherokee Purple		
	Day	Hue angle	Color Name; Hue
	D0	179	Aqua; blue
	D6	94.5	Bright green; green
	D8	11	Scarlet; red

Table 5. Days to maturity, dates and number of harvests per variety

Variety	Days to Maturity	Dates of harvest	Number of harvests
AUB1	May 11th -July 11th (61 days)	July 11th – Sep 1st	16
AUB2	May 11th – July 23rd (73 days)	July 23rd – Sep 1st	12
AUB3	May 11th -July 11th (61 days)	July 11th – Sep 1st	16
Indigo	May 11th -July 11th (61 days)	July 11th – Sep 1st	16
Cherokee	May 11th -July 11th (61 days)	July 11th – Sep 1st	16

AUB1, AUB3, Indigo and Cherokee had a similar number of days till first harvest (61 days from transplanting), as well as number of harvests (16). While AUB2, took a bit longer with 73 days till first harvest and has been harvested only 12 times (table 5).

D. Phenological development and Plant Vigor

The phenological development of each variety was measured by counting the total number of shoots, clusters and open flowers throughout the season (table 6). There was a block effect for the average number of shoots, clusters and open flowers. AUB3 was statistically different than the other varieties having had the highest average number of shoots in all three blocks. For the average number of clusters and open flowers, AUB3 and Indigo were statistically different than the other three varieties in all three blocks having the highest average number in all three blocks for AUB3 and blocks 1 and 2 for Indigo. Indigo did not thrive in block 3 as well as it did in the 1st two blocks due to the row being shaded by a tree branch.

Table 6. Phenological development of the varieties throughout the season

	Av. nbr of shoots[1]	**Av. nbr of clusters[2]**	**Av. nbr of open flowers[3]**
Block[*] 1	**17.71 [1,2]**	**6.53 [2]**	**5.59 [2]**
AUB1[**]	18.54[a]	6.13[a]	4.71[a]
AUB2	15.6[a]	3.83[a]	3.29[a]
AUB3	19.69[b]	8.27[b]	7.88[b]
INDIGO	19.38[a]	10.21[b]	9.15[b]
CHEROKEE	15.35[a]	4.19[a]	2.92[a]
Block 2	**18.68 [2]**	**6.49 [2]**	**4.7 [1,2]**
AUB1	17.94[a]	5.46[a]	4.29[a]
AUB2	18.29[a]	4.67[a]	3.21[a]
AUB3	22.38[b]	7.96[b]	6.27[b]
INDIGO	16.52[a]	9.33[b]	5.94[b]
CHEROKEE	18.27[a]	5.02[a]	3.81[a]
Block 3	**16.45 [1]**	**4.78 [1]**	**3.68 [1]**
AUB1	13.19[a]	3.71[a]	2.96[a]
AUB2	18.85[a]	4.23[a]	3.92[a]
AUB3	20.23[b]	6.94[b]	4.56[b]
INDIGO	13.58[a]	4.4[b]	2.96[b]
CHEROKEE	16.38[a]	4.65[a]	4[a]

*N: 120 observations/ block/ season
**N: 72 observations/ variety/ season

[1]± standard error 0.861. Means with different letters and number superscripts represent significant differences at $P<0.05$.

[2]± standard error 0.482. Means with different letters and number superscripts represent significant differences at $P<0.05$.

[3]± standard error 0.891. Means with different letters and number superscripts represent significant differences at $P<0.05$.

E. Leaf Scouting

1. Leaf pests

The main leaf pests observed during the season were pea leafminer (*Liriomyza huidobrensis*) and South American tomato pinworm (*Tuta absoluta*). Pea leafminer average leaf infection ranged from 14.9% for AUB2, being the least infected with galleries to 31.7% for AUB3. Statistically, AUB2 differed from all the other varieties (table 7). While South American tomato pinworm (*Tuta absoluta*) damage had no significant difference between varieties or blocks, the average infection throughout the season was 19.53%.

Minor leaf pests that were also scouted for include aphids and whiteflies. Their presence was minimal and lower than 1% throughout the season, with the number observed per pest per variety as well as the season average shown in table 8. Lacewing, a natural enemy of aphids, was observed on the field a total of 28 times between all five varieties, which is equal to a seasonal average of 0.10% per the five varieties.

Table 7. Average percent infection by pea leafminer during the season

Variety*	Av. % leaves infested[1]
AUB1	27.3[b,c]
AUB2	14.9[a]
AUB3	31.7[c]
Indigo	25.7[b]
Cherokee	28[b,c]

*N: 342 observations/ variety
[1]Mean ± standard error 0.01
Means with different letter superscripts represent significant differences at $P<0.05$

Table 8. Total number of insects present on leaves

	Total number observed on leaves throughout the season	Seasonal Av. (%)
Tomato hornworm eggs presence	82	0.34
Aphid presence	236	0.91
Whiteflies presence	211	0.87

2. Leaf diseases

Scouting for diseases was only done when the first symptoms of Early blight (*Alternaria solani*) were observed towards the end of July. The symptoms were initially observed on the cultivar Indigo and included black lesions on the leaves that were distinct to the disease followed by the yellowing of the whole leaf. The infection then spread to the stem causing brown lesions which eventually lead to the death of the plant.

F. Physiological disorders and fruit damage

1. Main disorders

Mature ripe fruits were scouted at harvest for physiological disorders, diseases and pests which rendered the fruits unmarketable. Three main physiological disorders; blossom end rot, growth cracking and zippering affected fruits. There was a variety x block interaction for blossom end rot. Block 1 was statistically different than blocks 2 and 3, which were similar. As for the varieties, Cherokee was statistically different, having the highest number of fruits affected by blossom end rot, while the remaining varieties where similar with Indigo having the lowest number (table 9). BER was most apparent in the beginning of the season and decreased towards the end when irrigation time was increased.

As for growth cracks, there was no variety x block interaction; blocks 1 and 3 were statistically different with block 2 being similar to both. As for the varieties, Indigo and Cherokee were statistically different with the latter having the highest number of fruits affected by growth cracks. AUB1, AUB2 and AUB3 were similar (table 10). This disorder affected the fruits throughout the season.

Zippering is a pollination problem that is caused by excessive high humidity and is more prominent in cooler weather. AUB1 and AUB2 were statistically different with AUB1 having the highest number of fruits affected by zippering, while AUB2 had the lowest. AUB3, Indigo and Cherokee were similar (table 11).

Table 9. Number of fruits affected by Blossom end rot

	Nbr of fruits affected by BER[1]
Block 1	**1.02^{2}**
AUB1	1^{a}
AUB2	0.5^{a}
AUB3	0.7^{a}
INDIGO	0.2^{a}
CHEROKEE	2.7^{b}
Block 2	**0.46^{1}**
AUB1	0.3^{a}
AUB2	0.3^{a}
AUB3	0.6^{a}
INDIGO	0^{a}
CHEROKEE	1.1^{b}
Block 3	**0.54^{1}**
AUB1	0.1^{a}
AUB2	0.5^{a}
AUB3	0^{a}
INDIGO	0^{a}
CHEROKEE	2.1^{b}

[1]± standard error 0.261. Means with different letters and number superscripts represent significant differences at $P<0.05$.

Table 10. Number of fruits affected by growth cracks

Variety	Nbr of fruits affected by Growth cracks[1]
AUB1	$0.367^{a,b}$
AUB2	$0.467^{a,b}$
AUB3	$0.167^{a,b}$
INDIGO	0.1^{a}
CHEROKEE	0.6^{b}

[1]± standard error 0.118. Means with different letters and number superscripts represent significant differences at P<0.05.

Block	Nbr of fruits affected by Growth cracks[1]
1	0.52^{2}
2	$0.32^{1,2}$
3	0.18^{1}

[1]± standard error 0.091. Means with different letters and number superscripts represent significant differences at P<0.05.

Table 11. Number of fruits affected by zippering

Variety	Nbr of fruits affected by Zippering[1]
AUB1	0.667^{b}
AUB2	0.133^{a}
AUB3	$0.367^{a,b}$
INDIGO	$0.333^{a,b}$
CHEROKEE	$0.333^{a,b}$

[1]± standard error 0.120. Means with different letters and number superscripts represent significant differences at P<0.05.

2. Minor disorders and pest damage

A lesser physiological disorder that affected some of the fruits was cat-facing which is due to exposure of fruits to low temperatures. It was not subjected to statistical analysis due to a very small number of affected fruits, about four, mainly of the AUB2 line. As for pests, caterpillar damage and chicken found on the farm caused major damage. Chicken seemed to favor the Cherokee variety.

G. Yield

There was a block effect for the number of mature ripe fruits (table 12). Block 3 was partially shaded and thus had the lowest yield and was significantly different than Block 2. Indigo had the highest number of mature ripe fruits in blocks 1 & 2 while AUB3 was higher in block 3. On the other hand, AUB2 had the lowest number of ripe fruits in all 3 blocks followed closely by Cherokee. The varieties AUB2 and Cherokee were statistically different than all the other varieties in all 3 blocks. Indigo Rose and AUB1 seemed to give significantly lower yield in block 3 due to the rows being shaded.

Table 12. Av. Number of ripe fruits harvested and total yield per plot (2.88m^2) throughout the season per variety

	[1]**Av. # of ripe fruits/ harvest**
Block 1	**11.61 [1,2]**
AUB1	15.31[b]
AUB2	3.19[a]
AUB3	13.12[b,c]
Indigo	20.88[c]
Cherokee	5.56[a]
Block 2	**14.21 [2]**
AUB1	14.88[b]
AUB2	3.06[a]
AUB3	16.94[b,c]
Indigo	29.94[c]
Cherokee	6.25[a]
Block 3	**7.81 [1]**
AUB1	9.69[b]
AUB2	2.94[a]
AUB3	11.56[b,c]
Indigo	9.94[c]
Cherokee	4.94[a]

[1]± standard error 2.857. Means with different letters and number superscripts represent significant differences at $P<0.05$.

Table 13. Yield related parameters for five varieties.

Variety*	Average yield (Kg/harvest/row)[1]	Average marketable yield (Kg/harvest/row)[2]	Average Unmarketable yield (Kg/harvest/row)[3]
AUB1	1.65^{c}	1.524^{b}	0.145^{ab}
AUB2	0.903^{ab}	0.679^{a}	0.224^{b}
AUB3	1.625^{bc}	1.534^{b}	0.089^{ab}
INDIGO	0.716^{a}	0.701^{a}	0.016^{a}
CHEROKEE	1.147^{abc}	0.71^{a}	0.437^{c}

Block **	Average yield (Kg/harvest)[4]	Average marketable yield (Kg/harvest)[5]
1	$1.291^{1,2}$	$1.052^{1,2}$
2	1.434^{2}	1.287^{2}
3	0.899^{1}	0.749^{1}

*N: 48 observations/ variety/ harvest
**N: 80 observations/ block/ harvest
[1]± standard error 0.189
[2]± standard error 0.174
[3]± standard error 0.044
[4]±standard error 0.146
[5]±standard error 0.135
Means with different letters and number superscripts represent significant differences at $P<0.05$.

The Indigo variety had the smallest average yield of 0.716 Kg/plot/harvest (table 13), total yield of 23.67 t/ha, marketable yield of 23.38 t/ha and lowest unmarketable yield/plot/harvest of 0.016 Kg with the smallest sized fruit weighing an average of 36.67g. It produced an average of 32 fruits per plant with 31 being marketable.

AUB1 and AUB3, having the same medium sized fruits, had the highest total yield with the latter having a lower rate of unmarketable fruit. Cherokee, a beefsteak type tomato with an average of 213.33 g per fruit, had the second highest total yield of 37.84 t/ha with only 23.58 t/ha being marketable thus the highest number of unmarketable fruits being that it was highly susceptible to blossom end rot, cracking and was preferred by the chickens found on the farm. This variety produced an average of 9 fruits per plant with 6 being marketable. No block effect was observed for these parameters.

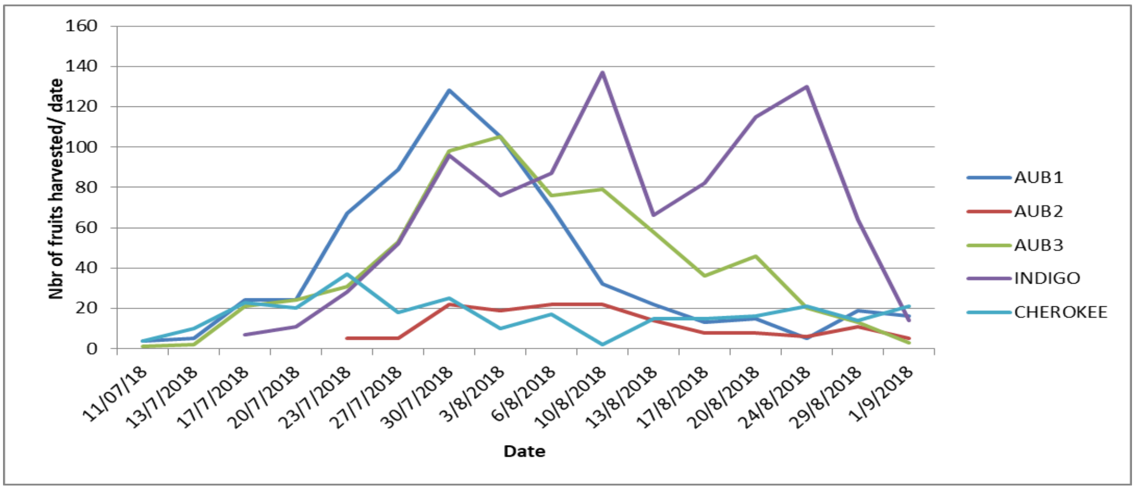


Figure 11. Bi-weekly yield (number of fruits/ harvest) per variety during the season

Varieties AUB1, AUB3 and Cherokee had 1 harvest peak while AUB2 had 2, between the end of July and the beginning of August. Indigo had 3 peaks during the season from the end of July till the end of August (fig 11). As for the number of fruits harvested from each variety, AUB2 had an average of five fruits harvested per plant, AUB1 and AUB3 had 21 and 22 respectively. Indigo had 32 and Cherokee had nine.

H. Quality at harvest

External and internal assessment of fruit quality was performed via post-harvest tests that included weight, size, firmness, brix, critic acid content, lycopene and grading (table 14, 15, 16 & 17). AUB2 had highest weight as well as the largest fruit size. Indigo cultivar had the smallest weight and fruit size, the lowest degrees brix but the highest lycopene content. Moving on to the cultivar Cherokee, it had the lowest firmness which means it was the mushiest in texture but had the highest degrees brix which meant it had the highest total soluble sugars and thus a sweeter taste than the rest. Moreover, AUB3 had the highest firmness and the lowest citric acid and lycopene content. Finally, AUB1 had the highest citric acid content while being within range for all the other parameters.

The same tests were performed before, during and after storage with firmness and brix only assessed on the final day since they are considered invasive procedures (table 20). Similar to the above results, AUB2 also had the highest weight and largest fruit size (table 19) while only being the firmest. Cherokee had the lowest firmness again however the second highest degrees brix. AUB3 on the other hand dropped in firmness after storage and AUB1 had the highest degrees brix instead of Cherokee (table 20). A comparison cannot be made between the degrees Brix taken at harvest and after storage since the fruits assessed were from different harvests, however it can be used as a reference to see that the Brix content did increase after storage.

The average % weight loss was also calculated between the first and last day of storage to make clearer the subtle change in weight that occurred during storage. The average percent weight (g) loss for each variety between day 0 and day 8 showed no statistical difference between the varieties while the average percent size (mm) loss for each variety showed that AUB2 and AUB3 were statistically different while AUB1, Indigo and Cherokee were similar (tables 21 & 22). Fruits were graded based on official national Libnor standards for tomatoes. The grading was based on size, homogeneity of color, phenological development and skin defects. Beginning with the quality at harvest, the cultivar Indigo was classified as grade 1 due to the fact that the fruit did not take its full violet color (due to the hot weather). Cherokee also had no fruits that were graded as Extra due to its susceptibility to cracking. While the AUB varieties 1, 2 & 3 had fruits in all 3 classes based on the criteria of each. AUB1 had the most graded as Extra, while AUB3 had the most graded as grade 1, AUB2 as grade 2. As for the fruits in storage, they were graded after 8 days. Only 11.10% of AUB1 fruits made it into the grade Extra while all the other varieties were placed in grades 1 and 2, meaning they were not at optimum size, color or firmness (table 18).

Table 14. Percentage of fruits in different grades for the varieties

Variety	Total		
	Extra	**Grade 1**	**Grade 2**
AUB1*	50.00%[a]	36.40%[a]	13.60%[a]
AUB2	21.40%[b]	42.90%[b]	35.70%[a]
AUB3	18.20%[b]	54.50%[b]	27.30%[a]
INDIGO	0.00%[c]	100%[c]	0.00%[b]
CHEROKEE	0.00%[d]	53.80%[b]	46.20%[c]

*N: AUB1: 22 AUB3: 22 Cherokee: 13 AUB2: 14 Indigo: 22
Different letter superscripts represent significant differences at $P<0.05$

Table 15. External assessment of fruit quality at harvest

Variety*	**Weight (g)**	**Size (mm)**
AUB1	129 ± 1.26[b]	65.85 ± 1.685[b]
AUB2	350 ± 1.58[d]	92.71 ± 2.113[d]
AUB3	137 ± 1.26[b]	67.40 ± 1.685[b]
INDIGO	36.6 ± 1.26[a]	42.19 ± 1.85[a]
CHEROKEE	214 ± 1.65[c]	81.09 ± 2.193[c]

*N: Aub1 = 22; Aub2 = 14; Aub3 = 22; Indigo = 22; Cherokee = 13
Means with different letters and number superscripts represent significant

Table 16. Internal assessment of fruit quality

Variety*	**Av. Firmness (lb)**	**Brix°**	**Citric acid content (mg/L)**
AUB1	1.65 ± 0.125[b]	5.42 ± 0.162[b]	0.401 ± 0.024[b]
AUB2	1.85 ± 0.156[b]	5.1 ± 0.203[a,b]	0.306 ± 0.024[a,b]
AUB3	2.68 ± 0.125[c]	4.92 ± 0.162[a,b]	0.275 ± 0.024[a]
INDIGO	1.06 ± 0.125[a]	4.45 ± 0.162[a]	0.351 ± 0.024[ab]
CHEROKEE	0.83 ± 0.162[a]	5.44 ± 0.211[b]	0.354 ± 0.024[ab]

***N**: 10 fruits/ variety

Means with different letter and number superscripts represent significant differences at P<0.05

Table 17. Lycopene content (mg/kg) of each variety

Variety*	**Av. Lycopene content (mg/kg)**
AUB1	24.163
AUB2	23.833
AUB3	21.251
INDIGO	29.363
CHEROKEE	26.953

**N: AUB1, AUB2, AUB3 and Cherokee = 1 fruit ; Indigo = 2 fruits

Table 18. Percentage of fruits in different grades for the varieties after storage for 8 days

Variety	Total		
	Extra	**Grade 1**	**Grade 2**
AUB1*	11.10%[a]	51.90%[a]	37.00%[a]
AUB2	0.00%[b]	25.00%[a]	75.00%[b]
AUB3	0.00%[b]	26.70%[a]	73.30%[b]
INDIGO	0.00%[b]	63.30%[b]	36.70%[c]
CHEROKEE	0.00%[b]	23.30%[c]	76.70%[d]

* N: AUB1: 27 AUB3: 30 Cherokee: 30 AUB2: 28 Indigo: 30

Different letter superscripts represent significant differences at P< 0.05

Table 19. External assessment of fruit quality after (8 days) of storage

Variety*	Weight (g)	Size (mm)
AUB1	125.93 ± 7.89[b]	64.66 ± 1.79[b,c]
AUB2	183.28 ± 7.62[c]	71.64 ± 1.73[c]
AUB3	102.50 ± 7.49[b]	59.44 ± 1.69[b]
INDIGO	23.33 ± 7.49[a]	34.93 ± 1.69[a]
CHEROKEE	115.67 ± 7.49[b]	66.46 ± 1.69[c]

*N: Aub1: 7; Aub2: 10; Aub3: 10; Indigo: 10; Cherokee: 10
Means ± standard error. Means with different letters and number superscripts represent significant differences at $P<0.05$

Table 20. Internal assessment of each variety after (8 days) of storage

Variety	Av. Firmness (lb)	Brix°
AUB1	1.27 ± 0.2[a,b]	5.79 ± 0.237[a]
AUB2	1.74 ± 0.177[b]	5.2 ± 0.209[a]
AUB3	0.98 ± 0.168[a]	5.11 ± 0.199[a]
INDIGO	0.84 ± 0.168[a]	5.17 ± 0.199[a]
CHEROKEE	0.66 ± 0.168[a]	5.32 ± 0.199[a]

*N: Aub1: 7; Aub2: 10; Aub3: 10; Indigo: 10; Cherokee: 10
Means ± standard error. Means with different letters and number superscripts represent significant differences at $P<0.05$

Table 21. Average % weight (g) loss per variety per 10 fruits after storage for 8 days

Variety[1]	Av. % loss/variety
AUB1	6.04[a]
AUB2	9.17[a]
AUB3	3.48[a]
Indigo	5.67[a]
Cherokee	4.49[a]

[1]± standard error 4.56. Means with different letters and number superscripts represent significant differences at $P<0.05$

Table 22. Average % size (mm) loss per variety after storage for 8 days

Variety	Av. % loss/variety
AUB1	3.17[a,b]
AUB2	8.31[b]
AUB3	1.63[a]
Indigo	5.94[a,b]
Cherokee	3.03[a,b]

[1]± standard error 1.663
[2]± standard error 2.494
[3]± standard error 0.503
[4]± standard error 1.722
[5]± standard error 0.726
Means with different letters and number superscripts represent significant differences at P<0.05

I. Sensory evaluation

Visual appearance is a critical factor that determines consumers' initial purchase however subsequent purchases are mainly determined by the whole sensory experience after tasting the product (Maul et al., 1997). The variety trial assessed five indeterminate open -pollinated tomato varieties which were also assessed visually and by taste by semi-trained consumers and a culinary chef.

For the general look and taste of each variety, there was no significant difference between the panelists (P>0.05) but there was a significant difference between the varieties (P<0.05). AUB3 and Indigo were statistically different; AUB3 was liked by the semi-trained consumers while Indigo received a neutral score on the general appearance and flavor scale. As for the semi-trained consumers' interest in buying these varieties (table 23), AUB3 and Indigo were statistically different with the latter having had the least number of people interested in buying it while AUB3 had the most. AUB1, AUB2 and Cherokee were statistically similar.

Likes and dislikes of the panelists are displayed in two figures separated into likes and dislikes. A spider plot was also generated showing the attributes given by the semi-trained panelists divided by appearance, texture and flavor. These all showed that AUB1 had a medium taste, AUB2 had good tomato aroma and was juicy, AUB3 had good tomato aroma and thick skin. While Indigo had an appealing color, was sweet and had a good tomato aroma and Cherokee had an attractive color and well-balanced flavor (fig 12, 13 & 14). The numbers denote the number of people that agreed upon a specific sensory attribute for a variety; for example, 11 consumers agreed that AUB1 was acidic while 10 consumers agreed that AUB3 was firm (fig 12). Fourteen out of 30 found Indigo to be bland while 23 out of 30 thought that AUB1 was bland (fig 13). The maximum number of consumers that agreed on an attribute were 11 out of 30.

Table 23. Appearance, flavor and interest in buying score each variety (based on scale)

Variety	Appearance & flavor Score	Interest in buying Score
AUB1	$5.60^{a,b}$	$3.8^{a,b}$
AUB2	$5.10^{a,b}$	$3.63^{a,b}$
AUB3	6.03^{b}	4.2^{b}
Indigo	4.83^{a}	2.93^{a}
Cherokee	$5.23^{a,b}$	$3.77^{a,b}$

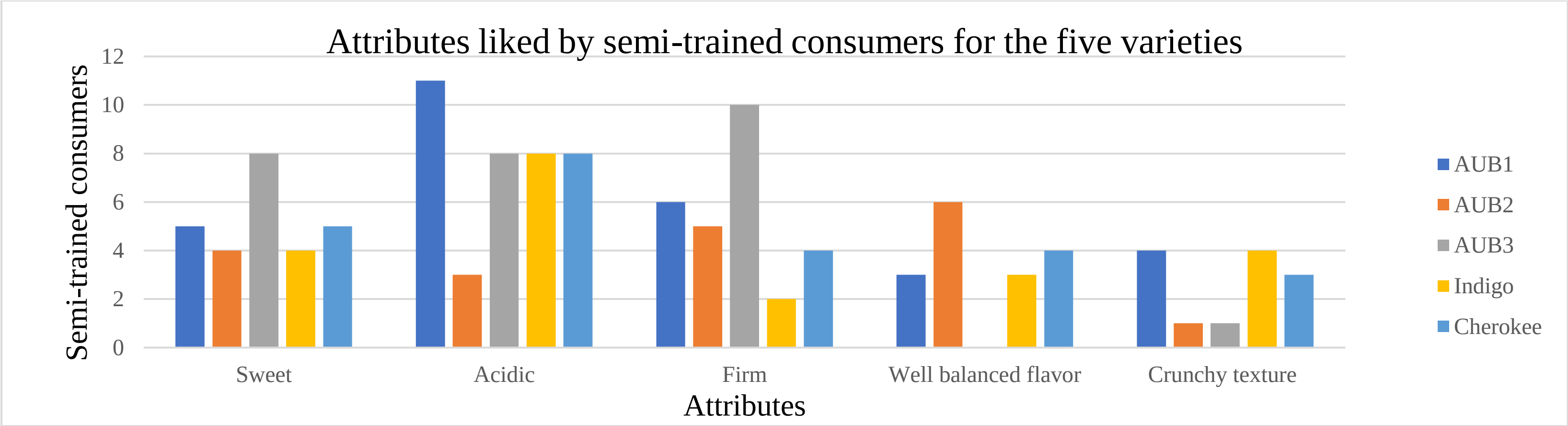


Figure 12. Sensory attributes liked by semi-trained consumers for the five varieties

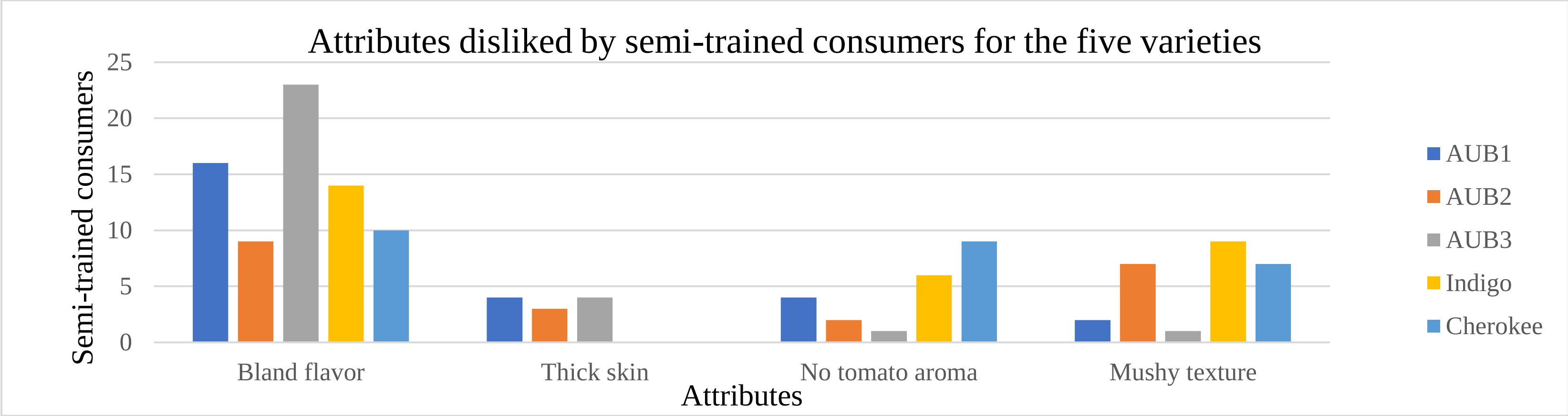


Figure 13. Sensory attributes disliked by semi-trained consumers for the five varieties

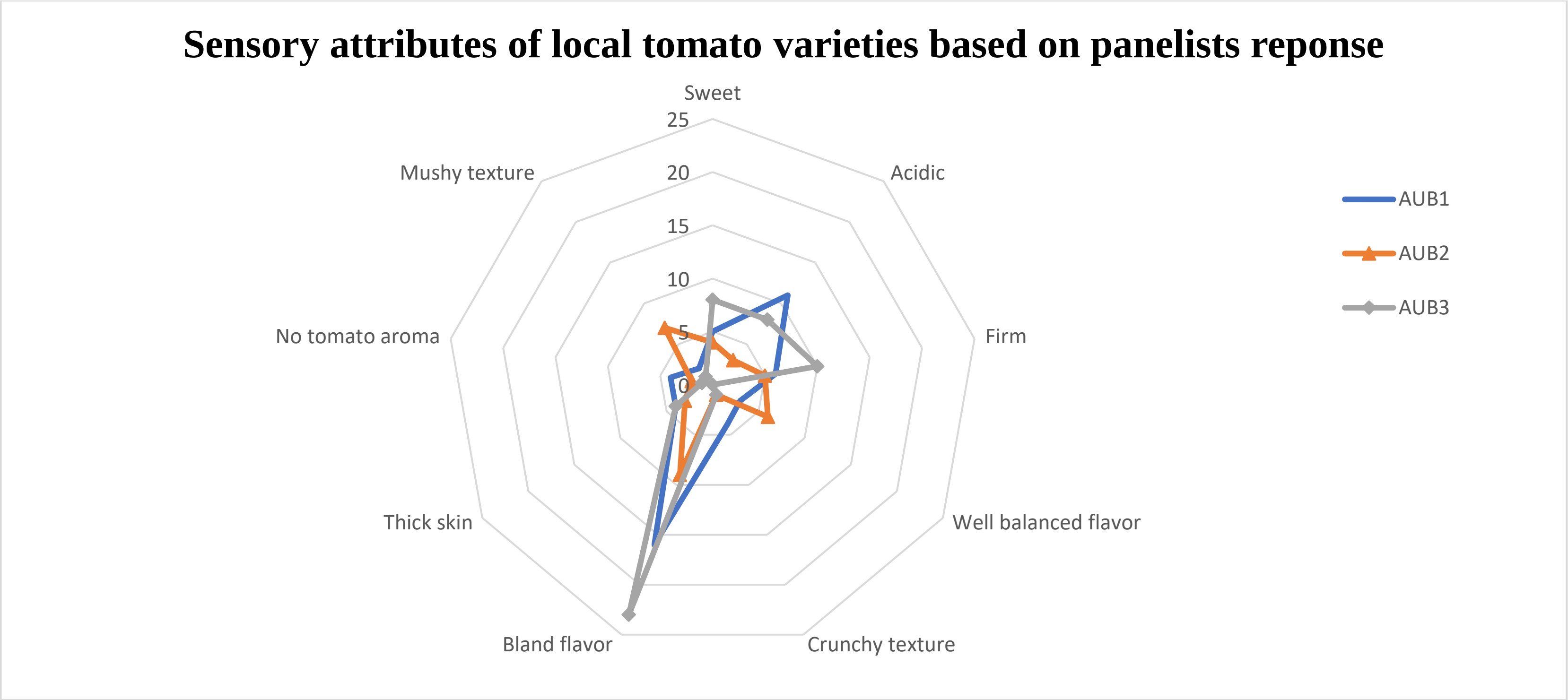


Figure 14. Sensory attributes of the five tomato varieties based on semi-trained consumers' response

Table 24. Flavor characteristics given by a culinary chef for each variety

Variety	Hint of sweet	Juicy	Good tomato aroma	Sweet plum taste	Well balanced acidity
AUB1	+	-	-	-	-
AUB2	-	+	-	-	+
AUB3	-	-	+	-	-
Indigo	+	-	+	+	-
Cherokee	+	-	-	-	+

Table 25. Appearance characteristics given by a culinary chef for each variety

Variety	Round	Good shape	Attractive color	Smooth peel
AUB1	+	-	-	-
AUB2	-	-	-	-
AUB3	-	+	+	-
Indigo	-	-	+	+
Cherokee	-	-	+	+

Table 26. Texture characteristics given by a culinary chef for each variety

Variety	Thick skin	Meaty	Good texture	Attractive color
AUB1	+	-	-	-
AUB2	-	+	+	-
AUB3	+	-	-	-
Indigo	-	-	+	+
Cherokee	-	-	-	+

Flavor, appearance and texture attributes were given by the culinary chef for each variety (tables 24, 25 & 26) where the plus (+) and minus (-) signs indicate if the variety expressed the specific attribute or did not. The chef also suggested some culinary uses for each variety. AUB1 and Indigo are good consumed fresh. AUB1 and AUB3 are good for roasting. While AUB2 and AUB3 are good for making sauces. He described Cherokee as a complete tomato, having a well-balanced flavor, smooth peel, an attractive color and nice for salads.

J. Cost benefit analysis

The cost of the production tasks on the field from pre-transplanting till post-harvest for one season on an area of 63.36m^2, with the production cost per m^2 at around 5,000 LBP excluding transportation cost (table 27).

Table 27. Production costs during one season

Task	Duration (days)	Labor Cost (LBP)	Cost (LBP/ 63.36 m^2)	Cost (LBP/ m^2)	Cost (LBP/ ha)
Ploughing Spreading compost	1	30,000	3,000	47.35	473,484.85
Transplanting	1/2	15,000	15,000	236.74	2,367,424.24
Hilling & Staking	1	30,000	12,000	189.39	1,893,939.39
Pesticides	3	90,000	10,000	157.83	1,578,282.83
Irrigation	1	30,000	11,000	173.61	1,736,111.11
Pruning & sucker removal	2	60,000	6,000	94.7	946,969.70
Fertilizer spraying	1	30,000	3,000	47.35	473,484.85
Scouting Phenology Harvest	14 1/2	435,000	192,000	3030.3	30,303,030.30
Transportation	4	120,000	-	-	-
Total	28	840,000	252,000	3977.27	39,772,727.27

Product	**Cost (LBP)**	**Cost (LL/63.36m²)**	**Cost (LL/m²)**	**Cost (LL/ha)**
Sulfur dusting	45,000	39,400	621.84	6,218,434.34
Wettable Sulfur	6,570	1,050	16.57	165,719.70
Copper	30,000	3	0.05	473.48
Bt	75,000	750	11.84	118,371.21
Fertilizer	17,250	16,200	255.68	2,556,818.18
Sticky traps	2,700	16,200	255.68	2,556,818.18
Total	176,520	73,603	1161.66	11,616,635.10

Table 28. Yield and profit in m^2 per variety and total

Variety	Yield (Kg/m^2)	Yield (t/ha)	Profit (LBP/m^2)	Revenue/m^2
AUB1	5.54	92.	36,960	31,828
AUB2	3	50.1	20,040	14,908
AUB3	5.36	89.4	35,760	30,637
Indigo	2.37	39.5	23,700	18,577
Cherokee	3.78	63.1	25,240	20,117
Average	5.61	56.1	20,000	23,213

The five varieties produced an average yield of 5.61 kg/m^2 (56.1 t/ha) and 290.8 kg over the full planted area for the five varieties in the full field through one season. The profit made per m2 collected to around 20,000 LBP, assuming that 1kg of AUB1, AUB2, AUB3 and Cherokee are sold are 4,000 LBP and 1kg of Indigo is sold at 6,000 LBP, which amounts to 1,036,800 LBP from the full planted area while the revenue equaled to about 720,000 LBP for the full planted area (table 28).

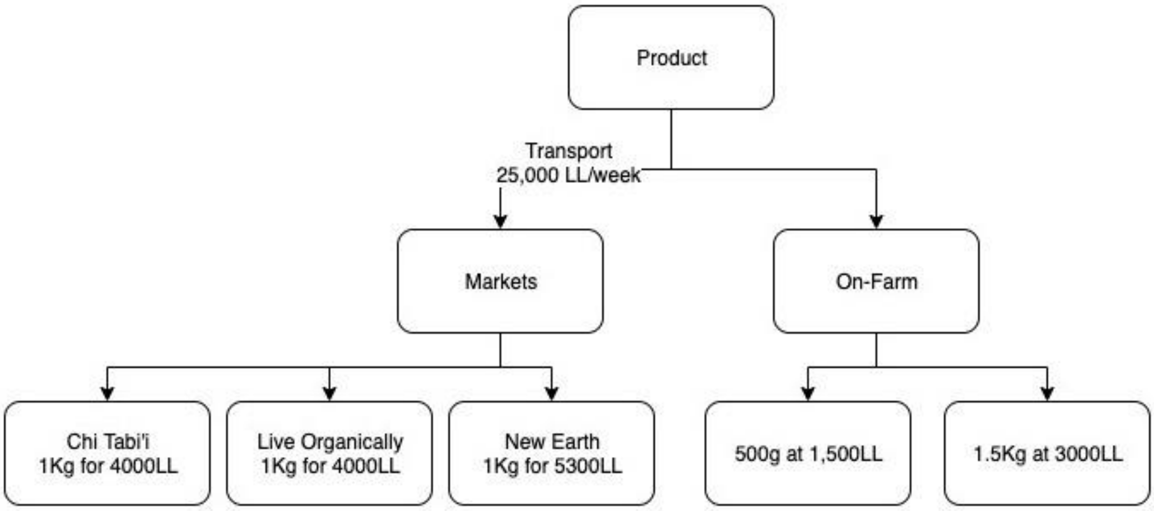


Figure 15. An illustration of the different channels harvested fruits are sold through.

The harvested tomato fruits are sold either on farm or in local organic markets in Beirut (figure 15).

CHAPTER V

DISCUSSION

A. Surveys on tomato traits preferences for growers and consumers

The tomato trait surveys for growers and consumers that were conducted before the experiment, helped us understand the desires and problems faced by both. They also gave us insight to what the consumers tolerated and what they did not when buying organic fruits and vegetables. The results made it clear that the majority were aware that organically grown produce are not perfect and around 77% tolerate imperfections in shape, color, firmness etc. Around 73% of consumers are willing to try new cultivars if they find them appealing and have an advantage over other varieties. This showed that not only are consumers more aware of the consequences of conventional farming but are also more open to change in terms of trying new shapes, sizes and colors. A good example is the variety Indigo Rose, bred specifically for organic farming that is different to what people are used to but has an added health benefit being the first variety to carry anthocyanins in its fruits (Oregon State University, 2012).

B. Phenological development and Plant Vigor

Days to maturity, refers to the number of days from transplanting till the first mature ripe fruit. Both Indigo Rose and Cherokee Purple took 61 days which is less than what is stated in the literature with Indigo taking between 70-90 days and Cherokee between 77-90 days. This may be due to the weather being warmer than usual. As for the AUB varieties, AUB1 and AUB3 also took 61 days while AUB2, a late variety, took 73 days and thus was harvested less times than the rest.

The number of shoots denotes the vegetative growth and indicated that AUB3 was the most vigorous in all 3 blocks having had the highest average number of shoots. While all the other varieties were the same in terms of shoot number. As for the number of open flowers and clusters, which denote the reproductive growth, it indicated that AUB3 had the highest growth in all 3 blocks while Indigo thrived in blocks 1 and 2. It did not flourish in block 3 as well as it did due to the row being shaded by a tree branch. While AUB1, AUB2 and Cherokee were statistically similar. None of the reviewed papers discussed this parameter however it showed that Cherokee Purple had the lowest growth which could be due to its susceptibility, the difference in the climate or soil composition.

C. Pest monitoring

AUB2 was significantly different than the other varieties, in that it was the least affected by pea leafminer damage. While the remaining varieties had between 25% and 32% leaves infested. However, there is little information available for the AUB lines, (except that they were bred to have resistance to *Tomato yellow leaf curl virus*). In literature, articles have only mentioned the times scouting took place, along with what was being sprayed however not in terms of actually counting the number of leaves infected by diseases or pests for the varieties Indigo Rose and Cherokee Purple. Nonetheless, Cherokee having the second highest average % infested leaves agrees with the literature that it is susceptible to physiological disorders and insects being an heirloom variety (Peet, 1992).

D. Physiological disorders and fruit damage

The variety Indigo Rose proved highly tolerant to physiological disorders such as blossom end rot, cracking and cat-facing thus had the lowest number of culled fruits. The percentage was 1.26% culled fruits in the experiment compared to 8.74% in the article by (Sidhu & Nandwani, 2017), both having the lowest percentage compared to the other tested varieties.

As for Cherokee Purple, it suffered the highest number of unmarketable fruits caused by growth cracks and blossom end rot which could be due to its large size and the fact that it is an heirloom variety. The % culled fruits in this trial were around 37.69% which is less compared to the experiment by (Sidhu & Nandwani, 2017) with an average of 74%. Also, less than what was mentioned by (Peet, 1992), who stated that more than 50% of the fruits were affected by cracking, cat-facing and insect damage. Multiple factors are thought to affect fruit cracking including genetic susceptibility, fluctuations, in plant water status and/or rapid fruit growth, high humidity and fruit subjected to high light intensity.

Again, there is no information on this parameter regarding the AUB lines for comparisons to be made however, AUB2 also suffered growth cracks due to its large fruit size reaching about 500 g per fruit.

E. Yield

Three of the varieties evaluated in this experiment were bred here at the University and thus have not been trialed before except in greenhouses in Lebanon. Therefore, the results can be compared to the yield of local Lebanese organic varieties. Both the greenhouse and open field productions ranged between 3 – 6 tons per dunum.

The comparison gave us a general idea of how they perform under the different growing conditions and managements. The AUB lines were also compared to the commercially imported varieties and based on the results showed that the AUB lines performed as good, if not better, than the imported cultivars. AUB1 and AUB3 were as vigorous as Indigo in terms of vegetative growth, were liked by the semi-trained panelists and had greater firmness. AUB1 had better average yield and AUB3 had greater marketable yield and better reproductive growth.

The cultivar Indigo Rose had an average fruit weight of 36.67g which was the smallest fruit in this experiment and weighed a bit less than the weight obtained by (Sidhu & Nandwani, 2017) of 39.87g. The total and marketable yield, which were 23.67 t/ha and 23.38 t/ha respectively, were way above what was achieved by (Sidhu & Nandwani, 2017) with 10.25 t/ha and 9.28 t/ha respectively which could be due to a 2.25 times higher planting density in this experiment. However, this variety had the highest marketable yield from the total yield which agreed with the paper. As for the average number of fruits per plant and marketable fruits per plant, they equaled to 32 and 31 respectively which were much higher than those obtained by (Sidhu & Nandwani, 2017) which equaled to 25 and 23 respectively.

Cherokee Purple on the other hand, had an average fruit weight of 213.33g, total yield of 37.84 t/ha and marketable yield of 23.58 t/ha. It also produced an average of 9 fruits per plant with about 6 being marketable. These results do not compare to those by (Sidhu & Nandwani, 2017), where the fruit weight was 100.32g, total yield was 7.62 t/ha, 5.99 t/ha of marketable yield, an average of 2.67 fruits per plant with 1.99 being marketable which could be due to a 2.25 times higher planting density in this experiment. Finally, as for the degrees brix which was an average of 5.38, it fell within the acceptable range of 3.5 – 5.5 (Peet, 1992).

They also don't compare to the results obtained by (Rivard, O'Connell, Peet, & Louws, 2010), who achieved higher total, marketable and unmarketable yields of 85.51 t/ha, 49.29 t/ha and 36.23 t/ha respectively due to a difference in climate. As well as $318.5*10^3$ fruits per ha with $148*10^3$/ha unmarketable unlike 254.9 and $69.81*10^3$/ha in the experiment however this trial had a lower number of unmarketable fruits per ha. The fruit weight in this field experiment for Cherokee was around 200g per fruit with around 9 fruits harvested per plant, which was not in range for either conventional or organic weights achieved by (Edlin, 2009) who obtained an average weight of 340g (per fruit) under the conventional system with around 1-2 fruits harvested and 300g under the organic system with an average of 2-3 fruits per plant. It was observed that as the number of fruits per plant increased, the average weight per fruit decreased.

Cherokee Purple had the highest percentage of unmarketable fruit which agrees with (Edlin, 2009) and (Rivard et al., 2010). As for the % marketable fruits, Cherokee produced around 60% marketable fruits throughout the season, which was more than that was obtained by (Francis & Stark, 2012) in the organic system with 36% and conventional system that produced 48% marketable fruits. This could be due to the difference in climate and soil which led to less fruits being affected by physiological disorders and pests.

F. Quality at harvest

None of the reviewed papers evaluated the shelf life of the varieties which is an important aspect especially for the consumers who are concerned about how the fruits store in the fridge. Assessing storage would let us know which variety stores the best and suffers the slowest deterioration over a specific period of time. The AUB3 cultivar had the best post storage results, having lost the least average weight and size while AUB2 fruits lost the most. As for the grading, there were no fruits graded as Extra after storage with the majority graded as grade 2 due to not meeting the grade Extra and grade 1 standards.

As for assessing the internal and external qualities at harvest, throughout storage and post storage, AUB2 had the largest and heaviest fruit while Indigo had the smallest and lightest. Cherokee produced the second largest fruit with the softest texture due to having the lowest firmness but was the sweetest in flavor which agrees with the (Edlin, 2009). It is important to note that fruits were not harvested at peak harvest for assessment and storage which might have contributed further to the deterioration of the fruit qualities of all the varieties except AUB1 which maintained a similar fruit weight and size throughout.

G. Sensory evaluation

The semi trained consumers seemed to visually enjoy the color of the Indigo fruit while expecting a different flavor, with only a few consumers stating they would be interested in buying this variety. Although Cherokee was not very productive during this experiment, consumers were still interested in it because of its unusual color and sweet flavor (being an heirloom variety) yet it also might not be the best choice for farmers to grow, at least not alone due to its susceptibility to BER and cracking. Finally, AUB2 was not too appreciated due to its large size being a bit inconvenient while

AUB1 and AUB3 were the most accepted due to their traditional color, shape and flavor.

Assessing the varieties through sensory evaluation wasn't commonly done. It helps growers know which variety was appreciated by the consumers and which weren't, and this helps him/her to know what to plant in the future.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

There is a lack of varieties bred specifically for organic agriculture thus the varieties being used by farmers often underperform due to being bred for production under conventional practices. From the surveys filled out by consumers and farmers, we tried to make their concerns and requests as the objective of this experiment in order to find suitable varieties depending on their needs to help them maximize their yield and profit while minimizing their losses. The varieties assessed were open pollinated with two commercially imported varieties bred for organic production.

Field scouting of the leaves and fruits as well as harvest, were important attributes for the growers whose main concerns were yield and susceptibility. Hence measuring the total, marketable and unmarketable yield as well as scouting for diseases and pests helped assess which varieties were the most productive and least susceptible to *Tuta absoluta* and Early blight among other pests and diseases. Cherokee Purple had the lowest performance in terms of yield and susceptibility to blossom end rot and growth cracks. Indigo Rose on the other hand was almost completely tolerant to physiological disorders with very high yield but had the smallest fruit in terms of size. AUB2 was not received the best by the semi-trained consumers due to its big size and bland taste.

While fruit quality at harvest including weight, size, firmness, brix, color and grade were measured at harvest and after storage for eight days, to compare the fruits flavor, appearance as well as shelf life. The shelf life, flavor and appearance were considered important attributes with AUB3 having lost the least weight and size.

In conclusion, Indigo Rose was high yielding, highly tolerant to arthropod pests, produced small fruits with high reproductive growth and high critic acid and lycopene content, thus would be recommended to growers who are looking for a high yielding and tolerant cherry type tomato cultivar. As for Cherokee Purple, it has a highly appreciated taste and appearance however is a bit difficult to produce by being low yielding and susceptible to BER and growth cracks hence could be recommended to growers whose consumers want to try a new, internationally appreciated variety. AUB1 and AUB3 both produced medium to high yield with fruits that have the typical tomato flavor and appearance which would be good for growers whose consumers prefer the more traditional tomato fruits. Finally, AUB2 was a late variety that produced the heaviest and largest fruit, low yielding, susceptible to growth cracks and was not very appreciated by the semi-trained panelists therefore would be suggested to growers whose markets are not targeting everyday consumers. A summary of the highest and lowest performing varieties for the different parameters (mentioned in the thesis) are found in table 29.

Finally, the trial should be repeated another year as well as in different regions and under greenhouse conditions to test the variability of their performance under different microenvironments.

Table 29. Highest and lowest performing varieties for the different parameters

Variety	Phenology	Susceptibility to pests	Susceptibility to physiological disorders	Average yield (t/ha)	Quality post storage	Appreciation by semi-trained consumers
AUB1	-	-	-Most affected by zippering	-High average yield/plot (16.5 t/ha)	-Highest % weight loss after storage	-Very appreciated due to having the traditional flavor & appearance
AUB2	-	-Least number of leaves infected by Pea leaf-miner	-2nd highest number of fruits affected by cracks	-Largest & heaviest fruits	-	-
AUB3	-Most vigorous (highest av. # of shoots) -Highest # of flowers & clusters	-Highest number of leaves infected by Pea leaf-miner	-	-High average yield/plot (16.25 t/ha) -Highest marketable yield -Highest average firmness	-Highest % firmness loss after storage	-Very appreciated due to having the traditional flavor & appearance
Indigo	- Highest # of flowers & clusters	-	-Highly tolerant	-Highest average number of ripe fruits/ plant -Highest lycopene content	-	-Least appreciated by semi-trained panelists
Cherokee	-	-	-Most susceptible to BER & cracks -Most preferred by chickens (on farm)	-Highest unmarketable yield -Highest Brix content	-	-Appreciated flavor

APPENDIX I

VARIETY PROFILE

AUB2

Indeterminate, OP

Days to maturity 73 days

Late variety

Color & Hue: 7; Scarlet, Red

Crack Susceptible

AUB1

Indeterminate, OP

Days to maturity 62 days

Color & Hue: 179; Aqua, Blue

AUB3

Indeterminate, OP

Days to maturity 61 days

Color & Hue: 8; Scarlet, Red

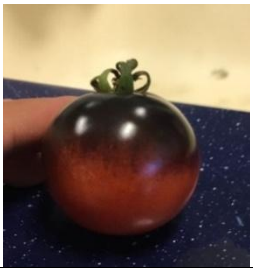
Indigo Purple

Cherry-sized

Indeterminate, OP

Days to maturity 61 days

Color & Hue: 8; Scarlet, red



Cherokee Purple

Heirloom

Indeterminate, OP

Days to maturity 61 days

Late variety

Color & Hue: 108.5; Aqua, blue

BER, Zippering Susceptible

APPENDIX II

SURVEYS

1. Consumer

Do you buy organic tomatoes regularly?	
17 out of 30 participants answered yes	56.70%
13 out of 30 participants answered no	43.30%

Are you loyal to a special place?	
10 out of 30 consumers answered yes	33.30%
20 out of 30 consumers answered no	66.70%

For what use do you buy organic tomatoes?	
24 out of 30 participants use for cooking	80.00%
18 out of 30 participants use for salad	60.00%
1 out of participants use for tomato paste	3.33%

Do you buy a different type of tomato?	
5 out of 30 participants answered yes	16.70%
25 out of 30 participants answered no	83.30%

Do you buy organic sauce, ketchup or any other processed product made from organic tomato?	
13 out of 30 participants answered yes	43.30%
17 out of 30 participants answered no	56.70%

How important is it to you that these products are made from organic tomato?	
8 out of 30 answered: Not important	26.70%
15 out of 30 answered: Somewhat important	50%
7 out of 30 answered: Very important	23.30%

Are these characteristics different if you wanted to buy conventional tomatoes?	
2 out of 30 answered yes	6.70%
28 out of 30 answered no	93.30%

How willing are you to buy new varieties that you did not know of before?	
22 out of 30 answered: Very willing 73.3%	73.30%
8 out of 30 answered: Somewhat willing	26.70%
Not willing	0%

Is there a variety that you knew before but can no longer find?	
1 out of 30 answered yes	3.30%
Small, plum-sized purple type	
29 out of 30 answered no	96.70%

Is there a time in the year when it was difficult for you to find organic tomatoes?	
2 out of 30 answered yes during the winter	6.70%
28 out of 30 answered no	93.30%

Is there a time in the year when organic tomatoes are more expensive than usual?	
7 out of 30 answered yes during the winter	23.30%
23 out of 30 answered no	76.70%

Do you tolerate default organic tomatoes?	
23 answered yes	76.70%
Firmness 3 people	
Shape 14 people	
Color 11 people	
Cracks 1 person	
Size 1 person	
7 answered no	23.30%

What would you like to see improved in organic tomato or processed tomato?	
24 (people answered)	Shelf life
1	Accessibility
10	Better firmness
1	Taste
2	Shape
2	Size

What makes you choose organic over conventional?	
12 (people answered)	Healthier
13	Flavor
7	Cleanliness
8	No pesticide use
2	Quality
2	More environmentally friendly
1	Presentation

How different are organic tomatoes from conventional?	
8 (people answered)	Taste
3	Shorter shelf life
7	Healthier
2	Presentation
1	Cleaner
3	Very different
5	Not different

What are the characteristics you are looking for when buying organic tomatoes?	
20 (people answered)	Taste
1	No need to peel
1	Smell
13	Color
2	Nutritional value
2	No pesticide
9	Shape
2	Shelf life
6	Firmness
1	Origin
1	Size

What will make you buy a new variety that you haven't tried before?	
1 (person answered)	GMO free
19	Curiosity
4	Unique
1	Price
2	No previous exposure
8	Display
4	Taste
1	Advantages

2. Grower

In which region are you situated?
2 out of the 5 are situated in Chouf
1 is situated in the South
1 is situated in Zaryyieh
1 is situated in Fatri

The farms are located on an altitude
30m (above sea level)
300m
400m
600m
700m

What is the local weather like?
Costal, Mediterranean & high temps

What vegetables other than tomatoes are organic?
all seasonal vegetables

When do you harvest?
4 out of 5 harvest in July
1 out of 5 harvests November to June

How many times do you harvest?
4 out of 5 harvest 2x/ week (depending on the weather)
1 out of 5 harvests 3x/ week

Level of education?
2 out of 5 reached high school level
1 out of 5 has an undergraduate degree
2 out of 5 have masters degrees

How many years have you been in business?
21
17
12
2
>1

How many employees do you have?
4 full time
1 full time/ 1-2 seasonal
5
1
8

How much land do you?
own: 8ha, 60 du, 8000m2
lease: 2 ac, 7 du, 50 du

Do you produce organic tomato?
5 out of 5 answered yes

For how long have you been producing organic tomatoes?
17 (years)
14
12
2
>1

What is the area in m2 used for organic tomatoes?					
open field:	2/3	2 du	around 3000m2	1/2 du	-
Covered:	1/3	3 du	-	-	4000m2

How much yield do you get from your organic tomatoes/season?
5-6 (tons/du/season)
8 tons
3 tons
2.56- 6.4 tons
0.265 tons/ 0.5 du

How much do you sell a kilo for?
2,500 LL
4,000 - 8,000 LL
250g - 2,000 LL
700 - 800 lira (lowest) / 2,000 - 4,000 LL (highest)
2,500 LL

Do you intercrop?
1 out of 5 answered yes
4 out of 5 answered no

What type of marketing do you use?
wholesale & export
Public market, stand at the farm, Independent retails, restaurants
public market & restaurants
public market
Basket, stand at farm, processors, restaurants

Do you consider you have easy access to interesting varieties adapted to organic management?
All farmers responded no (100%)

Do you use certified organic seeds?
4 out of the 5 answered yes 2 produce their own 1 imports from the US 1 imports from France 2 obtain them locally from Mashtal hiba & bzorona jzorona 1 out of the 5 answered no

Is there any variety that if you were to lose access to it, you would be in trouble?
4 answered no 1 answered yes; Roma type

Were there any varieties that were particularly interesting for your organic management that you do not find anymore?
4 answered no 1 answered yes

The problems related to varieties adapted to organic management are essentially:
3 out of 5 Sanitary aspect, Adequacy of yield & taste, Length of season adapted to your region 2 out of 5 Adequacy of yield & taste, Sanitary aspects, Length of season adapted to your region

What are the most important problems or aspects you want to improve in varieties for organic management?
3 out of 5: Resistance to pests and diseases 1 out of 5: More selection of organic pesticides & fungicides 1 out of 5: Market, pesticides able to use in organic

Do you do tests on your farm to assess varieties?
4 out of 5 answered yes
Only 1 assess tomato varieties: Roma type for processing to get the best sauce & Heirloom for resistance
1 out of 5 answered no

How do you proceed with your variety trial to assess these varieties?
By growing 200 seeds/plants as a trial to assess yield & customer approval
By growing different varieties for yield, resistance and customer approval

Are you interested in participating in variety trials under organic management?
5 out of 5 answered yes

Under what conditions?
To grow fall crops or early yield spring
To grow healthy plants and good yield

How many varieties do you plant?			
1st farmer	Variety	Type	Growing place
	Cherokee	Indeterminate	Covered + Open field
	German	Indeterminate	Covered + Open field
	Cherry	Indeterminate	Covered + Open field
	Zebra	Indeterminate	Covered + Open field
2nd farmer	Katrina	Indeterminate	Covered
	Smarty	Semi-determinate	Covered
	Soha	Determinate	Open field
3rd farmer	Cherry	Determinate	Open field
4th farmer	Jabaliyeh	Indeterminate	Open field
	American	Indeterminate	Covered
5th farmer	Roma type	Indeterminate	Open field

When you choose your seeds & varieties, what importance is given to:					
	1st farmer	2nd farmer	3rd farmer	4th farmer	5th farmer
Local seller	5	5	2	1	4
Adapted to climate & region	5	5	2	-	4
Fruit appearance	4	4	-	-	2
Time to harvest, earliness of variety	4	2	-	-	4
Not coming from a multinational company	3	3	-	-	-
Newness of variety	3	5	5	4	-
Heirloom variety	3	5	3	4	-
Seed quality & seed germination level	5	4	-	-	-
Organically certified seeds	4	5	5	5	5
Seeds produced locally	3	1	-	-	-
Yield	5	5	-	5	4
Resistance to diseases & virus	5	5	5	5	5
Resistance to pests	5	5	5	5	5
Taste	5	5	4	4	3
Firmness of the fruit	4	4	4	4	4
Size of the fruit	3	3	-	-	-

(1= least important; 5= most important)

APPENDIX III

SENSORY EVALUATION SURVEY

Tomato Tasting

Survey #: _________

Code #: __________

Instructions:

1. Please rinse your mouth before tasting.
Observe the sample in front of you and then taste a piece.

Taking into consideration the characteristics of the tomato sample in front of you, please indicate with an "**X**" the box that best represents your opinion

Dislike A lot	Dislike	Dislike A bit	Neutral	Like A bit	Like	Like A lot
❑	❑	❑	❑	❑	❑	❑

2. What did you like/dislike about this tomato? Indicate what you liked under the **(+)** sign and what you did not like under the **(-)** sign.

+	-
___________________________	___________________________
___________________________	___________________________
___________________________	___________________________

3. Would you be interested in buying the tomato variety that you have just tasted?

Not interested ❑ A Bit Interested ❑ Neutral ❑ Interested ❑ Very Interested ❑

BIBLIOGRAPHY

Acquaah, G. (2009). *Principles of plant genetics and breeding*: John Wiley & Sons.

Alda, L. M., Gogoasa, I., Bordean, D.-M., Gergen, I., Alda, S., Moldovan, C., & Nita, L. (2009). Lycopene content of tomatoes and tomato products. *Journal of Agroalimentary Processes and Technologies, 15*(4), 540-542.

Aldrich, H. T., Salandanan, K., Kendall, P., Bunning, M., Stonaker, F., Külen, O., & Stushnoff, C. (2010). Cultivar choice provides options for local production of organic and conventionally produced tomatoes with higher quality and antioxidant content. *Journal of the Science of Food and Agriculture, 90*(15), 2548-2555.

Ambang, Z., Mengue, S., Kosma, P., Asseng, C. C., & Dooh, J. P. N. (2016). Assessing the resistance of three tomato varieties to bacterial wilt and stem rot. *Journal of Experimental Agriculture International*, 1-13.

Boyhan, G. E., Tate, S., McNeill, R., & McConnaughey, J. (2014). Evaluation of tomato varieties under organic production practices in Georgia. *HortTechnology, 24*(2), 252-258.

Brady, K. (2011). *Yield and quality performance of eleven open pollinated and three hybrid tomato cultivars grown under organic management in Lajas Puerto Rico.*

Campanelli, G., Acciarri, N., Campion, B., Delvecchio, S., Leteo, F., Fusari, F., . . . Ceccarelli, S. (2015). Participatory tomato breeding for organic conditions in Italy. *Euphytica, 204*(1), 179-197.

Ceccarelli, S. (2014). GM crops, organic agriculture and breeding for sustainability. *Sustainability, 6*(7), 4273-4286.

Chiffoleau, Y., & Desclaux, D. (2006). Participatory plant breeding: the best way to breed for sustainable agriculture? *International journal of agricultural sustainability, 4*(2), 119-130.

Colley, M., & Dillon, M. (2004). The next great challenge: Breeding seeds for organic systems. *Organic Farming Research Foundation Information Bulletin. Winter*, 1.

Crespo-Herrera, L. A., & Ortiz, R. (2015). Plant breeding for organic agriculture: something new? *Agriculture & Food Security, 4*(1), 25.

Dawson, J. C., Murphy, K. M., & Jones, S. S. (2008). Decentralized selection and participatory approaches in plant breeding for low-input systems. *Euphytica, 160*(2), 143-154.

Desclaux, D. (2005). *Participatory plant breeding methods for organic cereals.* Paper presented at the Proceedings of the COST SUSVAR/ECO-PB workshop on organic plant breeding strategies and the use of molecular markers.

Edlin, D. J. (2009). Heirloom and hybrid tomato yield and quality in organic and conventional production systems. *Masters Theses*, 135.

FAOSTAT - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. 2017. Statistic of agricultural production. Retrieved from http://www.fao.org/faostat/en/#data/QC

Francis, P. B., & Stark, C. R. (2012). Heirloom tomato production in conventional and transitional-organic managed systems. *HortScience, 47*(8), 1034-1037.

Ganesan, M. (2001). Performance of tomato (Lycopersicon esculentum Mill.) varieties under organic farming in greenhouse and open field conditions during winter season of Tamil Nadu. *Madras Agricultural Journal, 88*(10/12), 726-727.

Giovannucci, E. (1999). Tomatoes, tomato-based products, lycopene, and cancer: review of the epidemiologic literature. *Journal of the national cancer institute, 91*(4), 317-331.

Gonzalez-Cebrino, F., Lozano, M., Ayuso, M., Bernalte, M., Vidal-Aragon, M., & Gonzalez-Gomez, D. (2011). Characterization of traditional tomato varieties grown in organic conditions. *Spanish Journal of Agricultural Research, 9*(2), 444-452.

Hoagland, L., Navazio, J., Zystro, J., Kaplan, I., Vargas, J. G., & Gibson, K. (2015). Key traits and promising germplasm for an organic participatory tomato breeding program in the US midwest. *HortScience, 50*(9), 1301-1308.

Horneburg, B. (2011). Organic plant breeding: achievements, opportunities, and challenges.

Lammerts van Bueren, E. T., Jones, S. S., Tamm, L., Murphy, K. M., Myers, J. R., Leifert, C., & Messmer, M. M. (2011). The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. *NJAS - Wageningen Journal of Life Sciences, 58*(3-4), 193-205. doi:10.1016/j.njas.2010.04.001

Legzdina, L., & Skrabule, I. (2005). Plant breeding for organic farming: current status and problems in Europe.

Luttikholt, L. W. (2007). Principles of organic agriculture as formulated by the International Federation of Organic Agriculture Movements. *NJAS-Wageningen Journal of Life Sciences*, *54*(4), 347-360.

Maul, F., Sargent, S., Huber, D., Balaban, M., Luzuriaga, D., & Baldwin, E. (1997). *NON-DESTRUCTIVE QUALITY SCREENING OF TOMATO FRUIT USING" ELECTRIC NOSE" TECHNOLOGY.* Paper presented at the Proceedings Florida State Horticultural Science.

MercyCorps. (June 2014). <FINAL Mercy Corps Lebanon Tomato Value Chain-Branded.pdf>.

Moose, S. P., & Mumm, R. H. (2008). Molecular plant breeding as the foundation for 21st century crop improvement. *Plant physiology, 147*(3), 969-977.

Naz, F., Haq, I. U., Asghar, S., Shah, A. S., & Rahman, A. (2011). Studies on growth, yield and nutritional composition of different tomato cultivars in Battal valley of district Mansehra, Khyber Pakhtunkhwa, Pakistan. *Sarhad J. Agric, 27*(4), 569-571.

Parmar, D. K., Thakur, D. R., Jamwal, R. S., & singh, G. (2018). Evaluation of Tomato Cultivars for Yield, Profitand Quality Performance in an Organic Management System in North Western Himalayas, India. *International Journal of Current Microbiology and Applied Sciences, 7*(10), 498-506. doi:10.20546/ijcmas.2018.710.054

Peet, M. (1992). Fruit cracking in tomato. *HortTechnology, 2*(2), 216-223.

Phillips, S., & Wolfe, M. (2005). Evolutionary plant breeding for low input systems. *The Journal of Agricultural Science, 143*(4), 245-254.

Rivard, C., O'Connell, S., Peet, M., & Louws, F. (2010). Grafting tomato with interspecific rootstock to manage diseases caused by Sclerotium rolfsii and southern root-knot nematode. *Plant disease, 94*(8), 1015-1021.

Rocha, M. C., Deliza, R., Ares, G., Freitas, D. D. G., Silva, A. L., Carmo, M. G., & Abboud, A. C. (2013). Identifying promising accessions of cherry tomato: a sensory strategy using consumers and chefs. *Journal of the Science of Food and Agriculture, 93*(8), 1903-1914.

RodrÍGuez-Burruezo, S., Prohens, J., RosellÓ, J., & Nuez, F. (2005). “Heirloom” varieties as sources of variation for the improvement of fruit quality in greenhouse-grown tomatoes. *The Journal of Horticultural Science and Biotechnology, 80*(4), 453-460.

Sánchez-Giráldez, H., Ramos, M., Zambrana, E., Tenorio, J., de la Cuadra, C., & Martín, I. (2010). *Traditional and commercial tomato cultivars evaluation for organic horticulture in two regions of Spain, Caceres and Madrid.* Paper presented at the XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on 933.

Shelton, A. C., & Tracy, W. F. (2016). Participatory plant breeding and organic agriculture: A synergistic model for organic variety development in the United States. *Elem Sci Anth, 4*.

Sidhu, V., & Nandwani, D. (2017). Cultivar Evaluation and Yield Performance of Tomato in an Organic Management System. *J Hortic, 4*(201), 2376-0354.1000201.

Singh, R. P., HUERTA-ESPINO, J., & William, H. M. (2005). Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. *Turkish Journal of Agriculture and Forestry, 29*(2), 121-127.

Toledo, D. S., Costa, C. A., Bacci, L., Fernandes, L. A., & Souza, M. F. (2011). Production and quality of tomato fruits under organic management. *Horticultura Brasileira, 29*(2), 253-257.

Van Bueren, E., Struik, P., Tiemens-Hulscher, M., & Jacobsen, E. (2003). Concepts of intrinsic value and integrity of plants in organic plant breeding and propagation. *Crop Science, 43*(6), 1922-1929.

Van Bueren, E. L. (2002). *Organic plant breeding and propagation: concepts and strategies*.

Verhoog, H. (2007). Organic agriculture versus genetic engineering. *NJAS-Wageningen Journal of Life Sciences, 54*(4), 387-400.

Watson, R. R. (2003). *Functional foods & nutraceuticals in cancer prevention*: Wiley Online Library.

Witcombe, J. R., Joshi, A., Joshi, K. D., & Sthapit, B. (1996). Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. *Experimental agriculture, 32*(4), 445-460.

Zdravkovic, J., Pavlovic, N., Girek, Z., Zdravkovic, M., & Cvikic, D. (2014). Characteristics important for organic breeding of vegetable crops. *Organic Agricultural Practices: Alternatives to Conventional Agricultural Systems*, 209.

Zhao, X., Chambers, E. t., Matta, Z., Loughin, T. M., & Carey, E. E. (2007). Consumer sensory analysis of organically and conventionally grown vegetables. *J Food Sci, 72*(2), S87-91. doi:10.1111/j.1750-3841.2007.00277.x