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TOLERANCIA A SALINIDAD Y ESTUDIOS PROSPECTIVOS DE MERCADO DE GENOTIPOS DE TOMATE (*Solanum lycopersicum* L.) NATIVOS DE MÉXICO

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La presente tesis, titulada: "**Tolerancia a salinidad y estudios prospectivos de mercado de genotipos de tomate (*Solanum lycopersicum* L.) nativos de México"** realizada por el alumno: **Peter Ladewig**, bajo la dirección del Consejo Particular indicado, ha sido aprobada por el mismo y aceptada como requisito parcial para obtener el grado de:

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TOLERANCIA A SALINIDAD Y ESTUDIOS PROSPECTIVOS DE MERCADO DE GENOTIPOS DE TOMATE (*Solanum lycopersicum* L.) NATIVOS DE MÉXICO

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Colegio de Postgraduados, 2016

RESUMEN

La salinidad del suelo es un factor de estrés que afecta el rendimiento de los cultivos en todo el mundo. Las plantas de tomate (*Solanum lycopersicum* L.) son conocidas por ser moderadamente sensibles a la salinidad. La presente investigación se llevó a cabo con la finalidad de caracterizar las respuestas agronómicas, fisiológicas y bioquímicas de variedades autóctonas de tomate mexicano ("tomate criollo") al estrés por salinidad y explorar los mercados regionales de estas variedades locales. Se probaron cuatro niveles de salinidad (0, 30, 60 y 90 mM de NaCl) de cuatro genotipos de tomate nativo de México (procedentes de Campeche, Oaxaca, Puebla, Veracruz) y un cultivar comercial denominado Vengador, bajo un sistema hidropónico en condiciones de invernadero. También se llevó a cabo una descripción del mercado del tomate criollo y comercialización en la región central de Veracruz. En general, el incremento en la concentración de NaCl disminuyó el rendimiento y el crecimiento de las plantas, pero aumentó algunos parámetros de calidad de la fruta. La variedad Veracruz mostró el mayor número de frutos, racimos y altura de planta, mientras que la variedad Puebla fue la más baja debido al estrés de la salinidad. La variedad Campeche respondió con la mayor disminución en el rendimiento en comparación con el control. La acidez titulable aumentó para la mayoría y la concentración total de azúcares para algunos genotipos, mientras que el valor CE aumentó para todos como respuesta a la salinidad. El estatus nutrimental de tallo, hojas, raíces y frutos se afectó de manera diferencial, principalmente entre genotipos. Se encontró una tendencia decreciente de K, Ca y Mg mientras que la concentración de Na aumentó debido al estrés por salinidad. La variedad Veracruz se postula como uno de los genotipos menos afectado por estrés salino. Respecto al estudio de mercado se encontró que los tomates comerciales de tipo Saladette tienen la mayor cuota de mercado, pero las variedades locales Citlale, Ojo de Venado y Chino Criollo se producen y venden localmente, a precios más altos y con mayores márgenes de reventas, pero la disponibilidad difiere dependiendo de los municipios y la estación del año.

Palabras clave: Solanaceae, tomate criollo, NaCl, estrés, estado nutricional, innovación

TOLERANCE TO SALINITY AND PROSPECTIVE MARKET STUDIES FOR NATIVE MEXICAN TOMATO (*Solanum lycopersicum* L.) GENOTYPES

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Colegio de Postgraduados, 2016

ABSTRACT

Soil salinity is a stress factor affecting crops all around the world by reducing yields and tomato plants (*Solanum lycopersicum* L.) are known to be moderately sensitive to salinity. The aim of this study was to characterize the agronomic, physiological and biochemical responses of native Mexican tomato landraces (“tomate criollo”) that are tolerant to salinity stress and to explore the regional markets of these landraces. Four landraces, from the Mexican states of Campeche, Oaxaca, Puebla and Veracruz, and one commercial cultivar, Vengador, were treated with 0, 30, 60 and 90 mM of NaCl in a hydroponic system in a greenhouse. In general increasing salinity stress decreased yield and growth of plants but increased some fruit quality parameters. The highest yielding genotypes under control conditions did not show the least decline in yield due to salinity stress, in fact the lowest yielding genotype, Veracruz, showed the lowest decline. Veracruz showed the highest number of fruits and trusses and plant height while Puebla displayed the lowest due to salinity stress. Campeche responded with the highest decrease in yield compared to control. Titratable acidity increased for most and total sugars concentration for some genotypes while EC value increased for all as a response to salinity. The nutrimental status of stem and leaves, divided by one upper and one lower part, roots and fruits was affected differentiated depending on genotypes. A declining tendency of K, Ca and Mg was found while Na concentration increased due to salinity stress. Veracruz appears to be one of the least negatively affected genotypes in our investigation. A comparative market study in the Region of the High Mountains of the state of Veracruz revealed that commercial Saladette type tomatoes have the highest market share but local landraces, Citlale, Ojo de Venado and Chino Criollo, are produced and sold locally as well, at higher prices and with higher reselling margins but availability differs depending on municipalities and season of the year.

Keywords: Solanaceae, landrace tomato, NaCl, stress, nutrient status, innovation

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CAPÍTULO I. INTRODUCCIÓN GENERAL

I.1. INTRODUCCIÓN

Los suelos salinos ocurren naturalmente en muchas partes del mundo. Las regiones áridas y semiáridas tienen una alta abundancia de suelos salinos debido a las bajas precipitaciones y una insuficiente lixiviación. El NaCl juega un papel importante en los procesos de salinización, ya que es la sal más abundante. Suelos con una CE superior a 4 dS m^{-1} (equivale a aproximadamente 40 mM de NaCl) son considerados, en definición, como salinos y cultivos crecidas bajo esta condición disminuyen significativamente sus rendimientos. La práctica del riego puede causar la salinización de los suelos, debido a la presencia de sales en altas concentraciones y más cuando existe una deficiente lixiviación y drenaje para el manejo de la misma. La salinización secundaria antropogénica es una amenaza para la seguridad alimentaria mundial (Eckhard *et al.*, 2012; Munns *et al.*, 1999). Se estima que las tierras afectadas por salinidad en una escala global son del 23% de la superficie total de cultivos y específicamente el 5% de toda la tierra cultivada es afectada por la salinidad secundaria (Munns *et al.*, 1999; Tanji y Wallender, 2012).

En México, el 5.4% de la superficie total agrícola es irrigada y el 13% está afectada por salinidad (Lázaro *et al.*, 2010; World Bank, 2016). Además, el 7% de los acuíferos mexicanos se enfrenta a problemas de salinización debido a la intrusión marina y a la erosión de evaporita (roca sedimentaria), en combinación con aguas congénitas y alta evaporación, así como baja precipitación (CONAGUA, 2015).

Por otra parte, el tomate (*Solanum lycopersicum* L.) es un producto agrícola importante y forma parte de una dieta diversificada en muchos países. Hay una conexión especial entre México y el tomate. El origen de los antepasados del tomate se encuentra en la región andina, especialmente en

Ecuador y norte de Perú, donde ocurrió la primera domesticación. Sin embargo, una segunda etapa final de domesticación tuvo lugar en Mesoamérica (Blanca *et al.*, 2015). La variedad botánica *Solanum lycopersicum* var. cerasiforme es el pariente silvestre más cercano del tomate, que se distribuye ampliamente en México (Lobato-Ortiz *et al.*, 2012). La palabra inglesa tomato o tomate en español y jitomate en algunas partes de México, tiene sus raíces en la palabra tomatl de la lengua náhuatl, hablada por los nahuas, el grupo étnico más numeroso del México actual (Jenkins, 1948). Además, el tomate desempeña un papel importante en el negocio agropecuario mexicano. La producción nacional para 2014 fue de 2.8 millones de toneladas aproximadamente, y el valor exportado fue de 20 mil millones de pesos mexicanos, convirtiendo a México en el líder mundial en exportación de tomate (SAGARPA, 2015).

La salinización afecta especialmente a la producción de tomate ya que la mayoría de los cultivares son moderadamente sensibles a la salinidad. Este cultivo, especialmente en suelos ligeros, necesita volúmenes de riego altos para obtener un adecuado rendimiento, aproximadamente 89 L de agua en sistemas de producción al aire libre por cada kilogramo de tomate producido (Haifa, 2016; Singh *et al.*, 2012; SAGARPA, 2012). La salinización afecta al crecimiento de la planta por tres mecanismos principales. Los primeros efectos negativos que se producen después de que las plantas están expuestas a la salinidad se atribuyen al estrés hídrico debido a un potencial osmótico reducido. Las plantas están limitadas en la absorción de agua adecuada y pueden mostrar síntomas similares al estrés por sequía. Además, las plantas pueden verse afectadas por la absorción excesiva de iones de Na^+ y Cl^-, causando síntomas de toxicidad a cierto nivel de iones acumulados en el citoplasma. Debido a la presencia excesiva de estos iones, pueden reemplazar otros iones en sitios de unión de enzimas e interrumpir así el metabolismo apropiado (Munns y Tester, 2008).

Algunas plantas se ven afectadas en mayor medida por iones Na^+ o Cl^-. La mayor restricción de importancia es la inducción del desequilibrio de iones. Los iones de Na^+ compiten con los iones de K reduciendo la disponibilidad de K en la planta. La homeostasis de K depende principalmente de la selectividad de las plantas para la captación de cationes y la capacidad para el flujo de Na del citosol a las vacuolas o apoplasma. Además, la absorción de Ca disminuye debido al estrés por salinidad, a su vez que el Ca es el segundo mensajero importante para las acciones de respuesta al estrés salino y ayuda a mantener la integridad del tejido celular (Eckhard *et al*., 2012). La tolerancia a la salinidad de los tomates está sujeta a investigaciones. Las plantas desarrollaron tres mecanismos principales de tolerancia para adaptarse al estrés de la salinidad. El primer mecanismo implica la adaptación al estrés osmótico de acción rápida, que provoca la disminución de la expansión celular en las puntas de las raíces y las hojas jóvenes, así como el cierre de estomas. Las plantas adaptadas mantienen la conductancia estomática y aumentan el crecimiento foliar, que es deseable solamente para las plantas bajo estrés salino, con la suficiente agua del suelo disponible para no generar una tensión adicional como la sequía. Una segunda manera de adaptarse al estrés por salinidad, es la capacidad de excluir el Na de hojas, principalmente la exclusión activa de Na en las raíces para prevenir la intrusión de Na en el flujo del xilema del tallo. La última adaptación es la tolerancia del tejido de las plantas a elevadas concentraciones de Na y/o Cl. Esto incluye la compartimentación de los iones en las vacuolas para evitar concentraciones tóxicas en el citosol, especialmente en las células mesófilas de las hojas (Munns y Tester, 2008). La toxicidad de Na es especialmente problemática en hojas donde se acumula después de entrar en la corriente de transpiración debido a que una planta, en condiciones normales, retiene 50 veces más agua en hojas (Munns *et al*., 2006).

Maas y Hoffman (1977) propusieron que el tomate puede tolerar niveles de salinidad hasta de 2.5 dS m^{-1}. Por su parte, Singh *et al.* (2012) reportaron una caída de 9.9% en el rendimiento por cada 1 dS m^{-1} excediendo el umbral, aunque este umbral no es aplicable a todas las variedades/cultivares y condiciones de investigación, debido a un alto rango de tolerancia al estrés salino en genotipos de tomate como se ha reportado en varias investigaciones (Magán *et al.*, 2008; Semiz y Suarez, 2015; Nouck *et al.*, 2016; Caro *et al.*, 1991).

Las variedades autóctonas como poblaciones heterogéneas, genéticamente dinámicas, han desarrollado cierta presión de selección en su región de origen y se caracterizan generalmente por su resistencia y adaptabilidad, más que por su alto rendimiento (Frankel *et al.*, 1995; Passam *et al.*, 2007). México ofrece una amplia diversidad de variedades de tomate, con capacidad de generar tolerancia al estrés por factores abióticos como la salinidad. Sin embargo, la mayoría de ellas son poco investigadas (Lobato-Ortiz *et al.*, 2012). Además, muchas variedades locales proporcionan un perfil único de compuestos volátiles, constituyentes nutricionales y buena apariencia visual de los frutos (Lobato-Ortiz *et al.*, 2012; Ruiz *et al.*, 2015; Andreakis *et al.*, 2004).

Antes de la introducción del primer cultivar de tomate híbrido "Single Cross" en 1946, los cultivares de tomate eran básicamente variedades de polinización abierta o variedades criollas, con una amplia gama de tamaños, formas y colores para diferentes propósitos de consumo, debido a sus características naturales (Bai y Lindhout, 2007; Dorst, 1946). Jenkins (1948) reportó que los tomates cultivados para exportación, son variedades que provienen principalmente de los Estados Unidos, y en México son cultivados principalmente en los estados de Sinaloa y Baja California, mientras que los tomates para el mercado nacional, son variedades mexicanas producidas principalmente en los estados de Veracruz, Puebla y Jalisco.

En la actualidad la producción de tomate se lleva acabo principalmente con cultivares híbridos altamente resistentes y de altos rendimientos, que presentan diferentes formas de frutas, cuyo mejoramiento genético es llevado a cabo por una docena de empresas globales compitiendo en el desarrollo continuo de nuevos cultivares, por lo que la innovación es clave para permanecer en los negocios (Bai y Lindhout, 2007).

Actualmente, no existe ninguna empresa mexicana especializada en la producción de semillas híbridas de tomate. El Servicio de Información Agroalimentaria y Pesquera (SIAP) reporta la producción de tomates de los tipos Redondo, Roma y Cereza entre otros, pero no consideran la producción de razas criollas mexicanas en sus informes (SIAP, 2016). Existe poca información científica sobre la producción de tomate de la raza criolla. Por otro lado, los estados de Oaxaca y Puebla son considerados centros de producción de variedades autóctonas, en los que se pueden encontrar diferentes formas y tamaños en los mercados locales (Bonilla-Barrientos *et al.*, 2014; Moreno-Ramírez, 2010).

La mayoría de estas variedades locales están apenas documentadas o descritas y no hay información disponible sobre el mercado de las razas criollas. Al respecto Sarukhán *et al.* (2009) declararon: "La biodiversidad representa el capital natural de la nación y es tanto o más importante que otros rubros, como el financiero o manufacturado, por lo tanto debemos promover y adoptar una cultura de su valoración en el contexto del desarrollo de México".

En este contexto y dado los cambios globales, por acción del cambio climático, el crecimiento demográfico y los recursos naturales limitados y cruciales como el agua y la tierra agrícola utilizable, entre otros, la presente investigación tuvo como objetivo, caracterizar las respuestas de variedades criollas de tomate mexicano a la salinidad y su potencial económico, así como obtener una visión de los mercados locales de estas variedades en México.

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CAPÍTULO II. GROWTH, YIELD AND FRUIT-QUALITY OF MEXICAN TOMATO LANDRACES IN RESPONSE TO SALT STRESS

II.1. INTRODUCTION

Salinity due to the excessive accumulation of salt in the rhizosphere is a global problem and is considered to be one of the most widespread reasons for soil degradation and yield limitation, with sodium chloride (NaCl) being the most abundant and soluble salt (Ladeiro, 2012; Manaa et al., 2011; Munns and Tester, 2008). Recent data on the global extend of salinity affected area is rare and existing data shows a wide range of values. It is estimated that 23% of the cultivated area is affected by salinity and 5% for all cultivated land is affected by secondary salinity, as a result of human activities (Munns et al., 1999; Tanji and Wallender, 2012). Activities to reclaim land affected by salinity and maintain nutrient balances are costly and energy intensive with only temporary success and the introduction of crop species with salt tolerance capable of producing economic yields are an important alternative (Caro et al., 1991; Singh et al., 2012).

Mexico's total area covers 1,972,550 square kilometers, and 54.9% of this area is used for agriculture. From the total agricultural fields, only 5.4% is irrigated, whereas 13% of this irrigated area is affected by salinity, most of the area in the north-western parts of the country (Lázaro et al., 2010; World Bank, 2016). Furthermore 46 Mexican aquifers (7% of the total) show problems related to salinity. Aquifers with presence of brackish water and saline soils predominate in the central basins of the north and the region of the Rio Grande, affected by low rainfall and high evaporation in combination with congenital waters and evaporite minerals of easy solubility. The peninsula of Baja California and the north-western region present aquifers with marine intrusions in the coastal zone (CONAGUA, 2014, 2015). In most of these areas, tomato (*Solanum lycopersicum* L.) is an important crop, and significant efforts are being carried out to increase productivity and exports.

Tomato is one of the most important agricultural products of Mexico, with a production of 3.28 million metric tons on 87.1 thousand ha in 2013, around 85% of the area using irrigation techniques and around 44% of the production originating in the north-western states of Sinaloa and Baja California (FAOSTAT, 2016; SAGARPA, 2010; SIAP, 2016). The tomato plant is considered moderately sensitive to salinity and according to Singh et al. (2012), most commercial cultivars demonstrate yield reduction at high salinity implied by electric conductivity values above 2.5 $dS{\bullet}m^{-1}$, but large variation among genotypes exists in regard to response to salinity (Manaa et al., 2011; Oztekin and Tuzel, 2011).

Mexico as place of final domestication of the tomato provides a high diversity of genetic resources of wild and native tomato varieties that allow discovering abiotic stress tolerance traits, including salt tolerance (Blanca et al., 2012; Lobato-Ortiz et al., 2012). Before the release of the first commercial tomato hybrid cultivar in 1946, breeding was performed with open pollinated varieties which could be considered landraces or heirloom (Bai and Lindhout, 2007). Interestingly, a high density of production of native Mexican tomato landraces is reported for the states of Veracruz and Puebla in the years before 1948 (Jenkins, 1948). While the majority of tomatoes produced nowadays in Mexico are commercial hybrid cultivars of the types Roma, Round and Cherry, there exists an insufficient documentation of production of native tomato landraces, locally named “tomate criollo”. These tomatoes are sold regionally and vary widely in shape, size, flavor and names. Lobato-Ortiz et al. (2012) classified some of these traditional native varieties according to fruit size and shape. There have been recent attempts to describe the agronomic diversity of native

Mexican landraces from the states of Oaxaca and Puebla in regard to total soluble solids and yield, among others. Some of these landraces show superior values of total soluble solids and even yields comparable to commercial hybrids (Bonilla-Barrientos et al., 2014).

Flores (2011) evaluated the potential for use in hydroponic greenhouse systems of native varieties collected in the state of Puebla for different electric conductivities in the nutrient solution. Estrada (2013) described yield potential and fruit quality parameters like pH value and total soluble solids, among others, for varieties collected in the states of Puebla and Veracruz and tolerance to salinity during germination, with some collections displaying superior salt-stress tolerance at this stage of plant development. Furthermore Sanjuan-Lara et al. (2015) reported significant difference in plant growth of native varieties collected in the state of Puebla to salt stress for young tomato plants. Therefore, in this study we aimed to carry out the analysis of plant growth, in terms of dry weight production, yield and the fruit quality aspects total soluble solids and the acidity as pH value of four Mexican native genotypes of tomato (i.e. Campeche, Oaxaca, Puebla and Veracruz) , and compare them with the well-known commercial Roma-Saladette type cultivar (i.e. Vengador), in response to four different concentrations of NaCl in the nutrient solution in hydroponics under greenhouse conditions.

II.2. MATERIALS AND METHODS

The experiment was conducted in 2015 in the Colegio de Postgraduados Campus Montecillo in Texcoco, State of Mexico (Mexico), under greenhouse conditions with drip irrigation system. The plants were obtained by germination of seeds originating from collections of traditional native landraces in four states of Mexico: Campeche, Oaxaca, Puebla and Veracruz, of the types Kidney, Ribbed, Kidney-Shaped, Chino Criollo (bell pepper shaped) and Citlale (star-tomato), respectively and one commercial hybrid of the Roma-Saladette type, Vengador (produced by Syngenta). The tomato type named by Lobato-Ortiz et al. (2012) as Citlale has various names throughout Mexico, including chaltomate or chaltomatl, jaltomate or jaltomatl, sitalillo, chitalillo and tomate silvestre (wild tomato) and might be identical to *Solanum lycopersicum* var. cerasiforme Dunal, Spooner, Anderson and Jansen (Jenkins, 1948; Rodríguez et al., 2009).

The nutrient solution was prepared according to Steiner (1984). The experiment was completely randomized with 10 replications per treatment. Seeds were sown in germination trays filled with peat moss based substrate and irrigated with tap water; pH was adjusted to 6 with 0.1 N NaOH. Twenty days after sowing plantlets were irrigated with Steiner solution at 50%. Plants were transplanted with 45 days of age in black polyethylene bags with 10 liter capacity filled with tezontle, an inert local volcanic gravel, with particle size between 1 and 20 mm. Plastic bags containing the inert substrate (tezontle) were spaced in four double rows, 160 cm between double rows and 35 cm between plants (35,714 plants ha^{-1}), and were guided with plastic rope to above installed wire at 250 cm above ground. Steiner solution was increased to 75% at the moment of transplant and to 100% sixty days after sowing, with a final electric conductivity of 2.4 dS m^{-1}. This solution was added with 30, 60 and 90 mM of NaCl for treatments to increase the electric conductivity to 5.4, 8.4 and 11.4 dS m^{-1}, respectively, for the plants 70 days after sowing. To protect plants during growth were applied agrochemicals when necessary, according to technical recommendations.

Suckers were cut when appearing and lower leaves when drying out. After 102 days of treatment plants were harvested and divided by leaves, stems and root. Leaves, stems and the roots were dried at 65 °C until constant weight in a forced air drying oven (Riossa HCF-125D; Guadalajara, Jalisco, Mexico). Dry weight of stems and roots were combined to obtain the shoot dry weight that was then used together with the root dry weight to calculate root/shoot ratio. The fruits harvested at fully ripe stage during the time of cultivation were weight directly after. With the fruit weights obtained the yield decrease was calculated. After taking the weight fruits were frozen at -80 °C for analysis of soluble solids (°Brix) and pH value of fruit juice. For these analyses five randomly picked fruits, at full maturity stage, belonging to landraces Oaxaca, Puebla, and Campeche, as well as for the hybrid Vengador were blended, with five replications, then filtered and the pH measured with a digital pH-meter (J.T. Baker Conductronic PC18; Phillipsburg, New Jersey, USA) and the Brix measured with a hand refractometer (Atago N-1E; Tokyo, Japan) in filtered juice. In case of the landrace Veracruz, 20 fruits (not only five) were used because of the small fruit size.

All data was subject to analysis of variance (ANOVA) using the GLM procedure of SAS ver. 9.3 (SAS Institute, 2011) to detect tomato response to NaCl and mean separation was realized with Tukey's range test. Predetermined significance level was set up with alpha equal to 0.05.

II.3. RESULTS AND DISCUSSION

Salinity causes three major effects in plants. First of all, plants suffer from water deficit (osmotic stress) due to a low water potential in the rhizosphere. The Na^+ and Cl^- ions which are absorbed excessively by plant roots cause an ion toxicity. As well, these ions trigger nutrient imbalance caused by lowered uptake of other essential nutrients or a reduced shoot transport and distribution within the plant. A certain growth inhibition process would be hard to address to one of these three effects as they impact plant organs in different ways and shift according to plant developmental stage, genotype and environmental conditions (Eckhard et al., 2012).

Under our experimental conditions, yield per plant was decreased for all genotypes with increasing salinity treatment levels, though the differences between 60 and 90 mM NaCl were not significant (Table II. 1).

Each genotype tested is affected by increasing salinity in different intensity. The osmotic stress affects plants more rapidly and is then followed by the ionic effect of excessive Na^+ and Cl^- ions uptake up to toxic concentrations, which may cause cell death in older leaves and results in reduced carbohydrate production (Munns and Tester, 2008). Osmotic stress in general slows carbon accumulation, has negative effects on the plants tissue expansion and leads to reduced cell number (Tardieu et al., 2011). The water flow into fruits is affected by high salinity levels due to lower water potential in the plant and thereby affects directly the fruit expansion rate (Johnson et al., 1992). The xylem plays an important role in water and nutrient influx to tomato trusses, with more than 75% being transported by xylem in the first eight weeks of truss development (Windt et al., 2009).

Table II. 1. Effect of NaCl applied in the nutrient solution of five tomato genotypes on the yield per plant, dry weight of leaves, stems and root, total soluble solid concentration and pH value.

Treatment	Yield (g/plant)	Leaf dry weight (g/plant)	Stem dry weight (g/plant)	Root dry weight (g/plant)	Soluble solids (g/plant)	pH
			Genotype			
Vengador	460.72 a	93.1a	36.6a	11.5c	9.6a	4.0c
Campeche	352.77 ab	71.8b	30.3b	13.9bc	9.6a	4.0c
Oaxaca	353.64 ab	65.6b	27.8b	19.4ab	6.5c	4.0b
Puebla	304.76 b	64.1b	27.2b	18.8ab	7.7b	4.1a
Veracruz	21.45 c	98.5a	39.1a	23.8a	10.4a	4.0c
			NaCl Concentration			
0 mM	609.59 a	104.1a	40.6a	24.7a	6.8d	4.1a
30 mM	311.32 b	91.4b	37.4a	20.8a	8.3c	4.0b
60 mM	173.59 c	65.3c	28.2b	14.1b	9.3b	4.0b
90 mM	106.51 c	53.7d	22.6c	10.3b	10.8a	4.0b
			P values from ANOVA			
Genotype	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
NaCl Concentration	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interaction	<0.0001	<0.0001	<0.0001	0.0007	0.0023	<0.0001

Genotype	NaCl concentration (mM)	Yield (g/plant)	Leaf dry weight (g/plant)	Stem dry weight (g/plant)	Root dry weight (g/plant)	Soluble solids (°Brix)	pH
Vengador	0	870.0 a	128.4 a	50.3 a	17.1 a	7.3 b	4.1 a
	30	480.0 b	116.6 a	47.4 a	14.9 a	10.0 a	4.0 ab
	60	242.5 bc	70.4 b	28.5 b	7.0 b	10.9 a	3.9 b
	90	180.8 c	57.1 b	20.2 b	7.0 b	10.2 a	3.9 b
Campeche	0	840.5 a	85.5 a	32.4 ab	15.9 a	8.4 a	4.1 a
	30	257.0 b	87.3 a	36.1 a	16.0 a	8.8 a	3.9 b
	60	157.8 b	63.9 b	29.2 bc	13.6 a	9.9 a	3.9 b
	90	82.5 b	50.4 c	23.5 c	10.3 a	11.4 a	3.9 b
Oaxaca	0	792.3 a	102.1 a	40.1 a	20.0 a	4.6 c	4.2 a
	30	387.5 b	61.5 b	25.9 b	22.9 a	5.6 bc	4.0 b
	60	189.1 b	59.0 b	26.8 b	18.4 a	6.2 b	4.0 b
	90	110.7 b	39.7 b	18.2 b	16.3 a	9.5 a	3.9 b
Puebla	0	508.5 a	75.0 a	29.7 a	28.4 a	5.0 c	4.2 a
	30	386.4 ab	75.8 a	31.3 a	21.5 ab	6.9 b	4.1 b
	60	226.5 bc	53.9 b	24.8 ab	15.8 ab	8.4 b	4.2 a
	90	118.0 c	51.6 b	23.0 b	9.5 b	10.6 a	4.1 ab
Veracruz	0	28.1 a	129.3 a	50.5 a	42.1 a	8.6 d	4.0 a
	30	22.2 a	115.7 a	46.1 a	28.7 ab	10.0 c	4.0 b
	60	17.4 a	79.1 b	31.7 b	15.7 bc	10.9 b	4.0 a
	90	16.1 a	69.7 b	28.0 b	8.6 c	12.2 a	3.9 c

Values of leaf, stem and root dry weights, soluble solids concentration and pH value are means of five repetitions; yield per plant is a mean of ten repetitions. Distinct letter after means in each column and genotype indicate significant differences among treatments for the upper part, for the lower part for each genotype (Tukey; $P \leq 0.05$).

Tomato plants exposed to salt stress show a reduced xylem exudation flow by a factor of 17 to 20 compared with the control plants (without salt stress), and increased ion concentrations in the xylem sap rose by a factor of 2 to 3 when exposed to 50 mM NaCl (Kafkafi, 1991). Singh et al. (2014) demonstrated that genotype and elevated salinity in the substrate, as well as the combination of both, affect tomato fruit yield, average fruit weight and number of fruits per plant significantly. Nouck et al. (2016) reports that depending on tomato cultivar yield reduction at 50 mM NaCl compared with control may be linked to decreased number of fruits per plant, but not for all cultivars investigated. Plants exposed to salinity stress over months may show reduced formation of florets, resulting in reduced fruit set (Munns and Tester, 2008). At control conditions Vengador showed the highest yields, 31.07 t ha^{-1}, followed by Campeche (30.04 t ha^{-1}), Oaxaca (28.29 t ha^{-1}), Puebla (18.18 t ha^{-1}) and Veracruz (1 t ha^{-1}). This order changes when applying NaCl. At the 30 mM level Vengador still yields the highest (17.14 t ha^{-1}), followed by Oaxaca (13.86 t ha^{-1}), Puebla (13.79 t ha^{-1}), Campeche (9.18 t ha^{-1}) and Veracruz (0.79 t ha^{-1}). Among all five genotypes evaluated, Vengador yields the highest for all treatments, whereas Veracruz yields the lowest (Table II.1). This tendency gives evidence to a high yielding performance of modern hybrid cultivars even at elevated salinity stress conditions. Veracruz is the only genotype without a significant decreasing effect of the treatments on the yield.

The Veracruz native variety was the only small-fruited genotype in this investigation and displayed an irregular growth with high sucker production. In traditional production systems plants are grown as determinate in bushy forms with higher potential yields. Instead, in our study all plants were grown as usual in modern production systems for comparative and reproducible reasons. Landraces usually cannot compete with modern hybrid cultivar yields (Jenkins, 1948; Caro et al., 1991; Brugarolas et al., 2009), but instead, they may provide different flavors, nutrient properties and represent a crucial source of genetic variability for breeding approaches. When exposed to 30 mM NaCl , the landraces Veracruz, Puebla, Oaxaca and Campeche, and the cultivar Vengador showed a decreased yield of 21%, 24%, 51%, 69% and 45%, respectively, in comparison to the control. When 90 mM NaCl were applied, the native variety Veracruz shows the least decrease in yield with a 43% reduction, while the Campeche showed the highest decrease with 90% (Fig. 1), both in comparison to the control (without NaCl). Tomato genotypes with high yields at control conditions as well has large fruited genotypes tend to be more negatively affected by increasing NaCl stress (Caro et al., 1991), which is in full agreement with our results. Magán et al. (2008) demonstrated different yield responses for two cultivars at various electric conductance influenced by NaCl. Tomato genotypes display different tolerance to salinity. Genotypes resistant to high salinity are used as root stocks to improve salinity tolerance and thereby productivity. The small-fruited botanical variety cerasiforme, wildly dispersed in Mexico, is considered more tolerant to salt stress than most commercial cultivars. Such botanical variety was less affected when exposed to 35, 70 and 140 mM NaCl than commercial cultivars were (Caro et al., 1991; Di Gioia et al., 2013; Nouck et al., 2016).

Accordingly, Bolarín et al. (1993) showed that tomato cultivars, including landraces, may display similar responses with decreasing yield as salinity levels increasing, though differences between the genotypes are evident. Although Vengador showed the highest yields at all treatment levels, it did not show the lowest yield decrease (Figure II. 1). Despite, Veracruz showed the least reduction in yield under salinity stress and thus displayed the highest salinity tolerance regarding yield, followed by Puebla, Vengador and Oaxaca. Campeche demonstrated to be the most sensitive genotype upon NaCl exposure under our experimental conditions (Figure II. 1.).

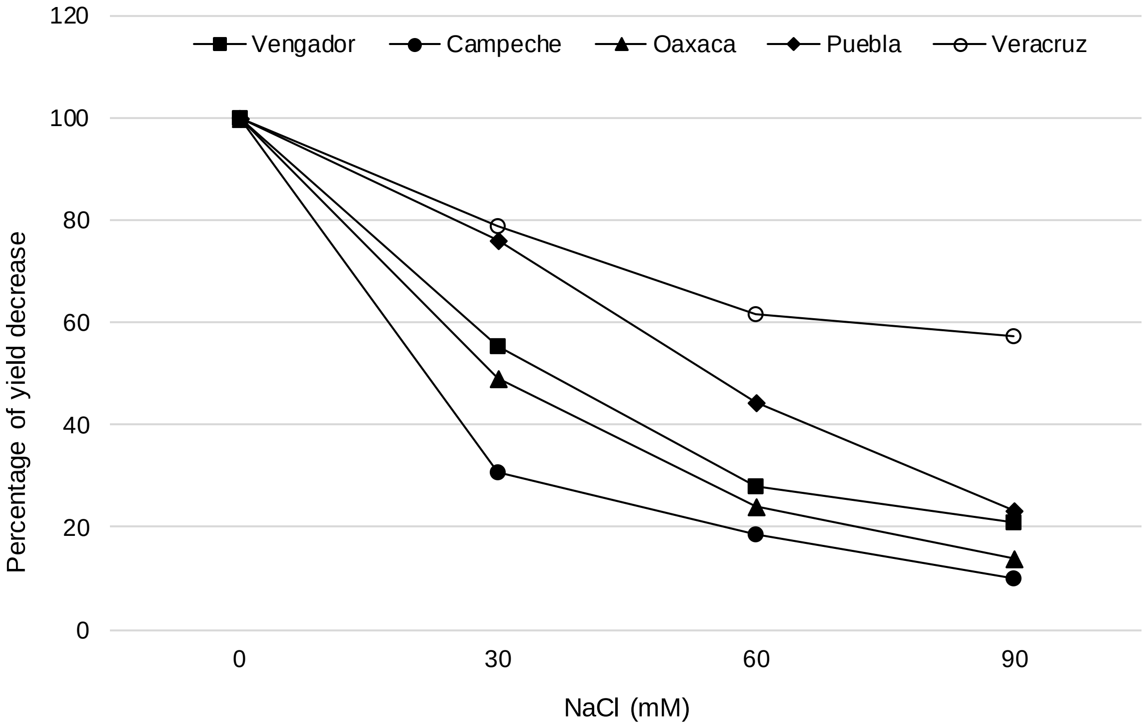

Figure II. 1. Percentage of yield decrease of five tomato genotypes in response to increasing concentrations of NaCl in the nutrient solution in hydroponics. Values are means of five measurements.

Root dry weight decreases with treatments of 60 and 90 mM by 43% and 58%, respectively compared to the control (Table II.1). Veracruz developed highest root dry weight at control conditions and when exposed to 30 mM NaCl and Oaxaca for 60 and 90 mM Nacl, while Vengador developed the lowest for all treatments with NaCl. Veracruz also showed the highest dry weight production for leaves and for stems at control conditions and Vengador follows with second highest dry weight for all plant parts, except roots. Puebla displayed the lowest dry weight production of stems and leaves for all treatments but the 90 mM, while Oaxaca did so for the 90 mM treatment. Leaf dry weight decreases significantly for each treatment of salinity and stem dry weight decreases significantly at the 60 mM treatment and again at 90 mM (Table II.1).

Tomato total plant dry weight decreases due to reduced growth with increasing salinity stress levels (Maggio et al., 2007). The decline of dry weight for roots, shoots and leaves was investigated by

Pérez-Alfocea (1993), demonstrating the existence of significant variations among cultivars and a landrace evaluated. Root and shoot dry weight of salt tolerant tomato cultivars may not be affected by salinity concentrations up to 200 mM NaCl, while moderately tolerant and sensitive cultivars show decreased dry weight with increasing salinity stress in different intensity (Nouk et al., 2016). In our study, the root/shoot ratio declines sharply for Veracruz and Puebla with increasing salinity. Vengador and Campeche maintain the ratio and Oaxaca shows high variability with an increasing ratio tendency (Fig II. 2).

With the exception of Oaxaca, these observations are contrary to those reported by Maggio et al. (2007), who observed an increasing root/shoot ratio with increasing salinity levels. Plants in such investigation were younger than plants evaluated in our study but Cruz and Cuartero (1990) showed that plants in various stages of development tend to increase root/shoot ratio. Tuna et al. (2007) demonstrated increased root/shoot ratio for one tomato cultivar exposed to75 mM NaCl with plants harvested at fruit-set stage. Pérez-Alfocea et al. (1993) showed that root and shoot dry weight decline in response to NaCl stress, and such decline is more evident when plants are exposed to this stress for longer time, while the intensity of dry weight decrease depends on the selected genotype. Root and shoot dry weight are negatively affected by increased salinity but salinity decreases shoot dry weight to greater extent than root dry weight (Cuartero and Fernández-Muñoz, 1999; Munns and Tester, 2008).

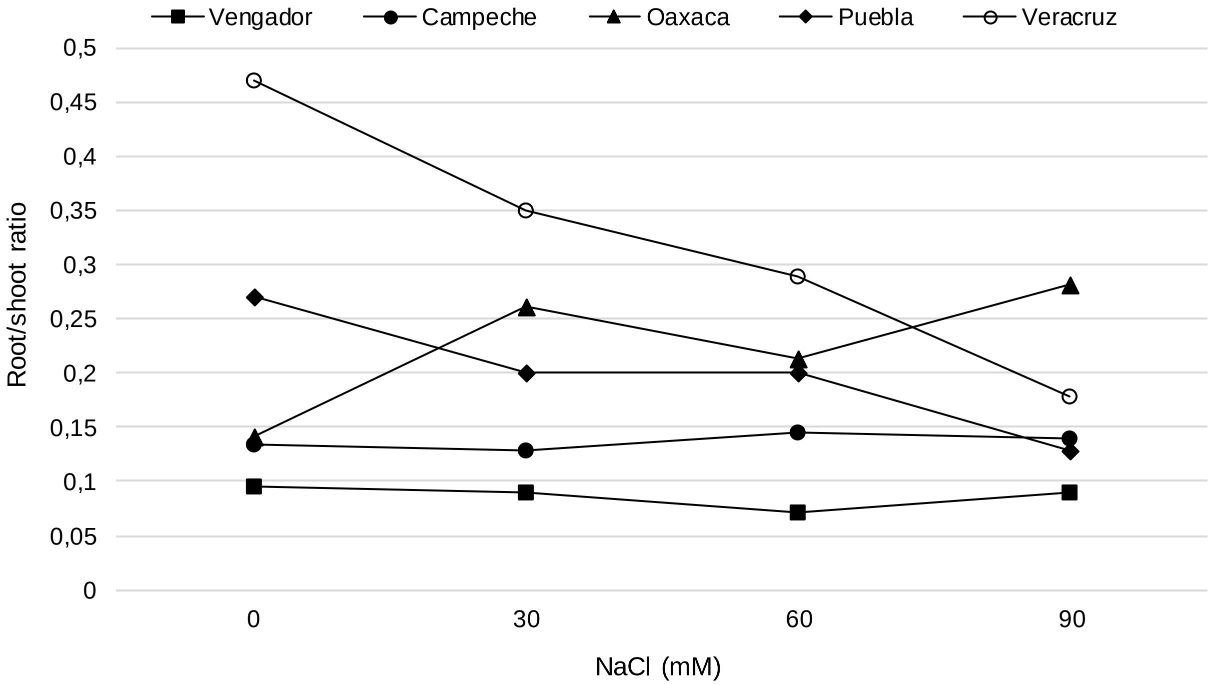

Figure II. 2. Root/shoot ration of five tomato genotypes in response to increasing concentrations of NaCl in the nutrient solution in hydroponics. Values are means of five measurements.

As shown herein, genotypes may show different responses at a much later stage of plant development. Only the Oaxaca plants has an increasing tendency in regard to root/shoot ration with increasing salinity levels. Puebla and Veracruz show an opposite response with decreasing root/shoot ratio and Vengador and Campeche do not change root/shoot ratio at greater extent under salt stress. Root/shoot ratio may vary greatly among tomato genotypes in response to salinity stress and this ratio may be an important factor to determine salinity tolerance and selection of elite genotypes for breeding proposes (Cruz and Cuartero, 1989; Dasgan et al., 2002; Nouk et al., 2016). Foolad and Lin (1997) state that depending on plant species, cultivar and environmental condition salinity tolerance is controlled by various mechanisms leading to an improved or worsened plant performance during plants growth. Tomato tolerance to salinity at a certain stage of plant development is not necessarily connected to salt tolerance at another stage of development (Foolad, 2007). This circumstance makes comparison with other investigations difficult because not only is each investigation subject to different climate conditions and cultivation methods but plants are also evaluated at different stages of development with different duration of salinity treatments at different concentrations.

Another aspect is the concentration of soluble solids which showed high variation among genotypes. Veracruz showed the highest concentration followed by Campeche and Vengador, without significant differences between the three. Puebla showed significant lower concentration and Oaxaca the lowest (Table II.1). The NaCl levels caused a significant increase of soluble solids in all concentrations evaluated. Moreover tomato fruits varied widely in pH among genotypes tested. Puebla showed significantly the highest pH values, followed by Oaxaca. The other three genotypes show similar low pH values (Table II.1). Evidently, salinity causes a significant decrease of pH values. Tomato cultivars and especially landraces demonstrate a high range in fruit´s sugar and acid profile (Casals et al., 2015). Cuartero and Fernández-Muñoz (1999) showed an increase of acidity and total soluble solids with increasing electric conductivity and reported a higher tomato fruit quality as a result of salinity exposure. Accordingly, tomato fruit acidity and total soluble solid concentration increased significantly in tomato plants exposed to salt stress (Del Amor et al., 2001; Brasiliano et al., 2006; Magán et al., 2008). Fruits with high acidity and sugar concentration are perceived as full in flavor, while those with high acidity and low sugar concentration present a tart flavor and sweet fruits without acidity are tasteless (Grierson and Kader, 1986). An increase of total soluble solids concentration with increasing electric conductivity, has also been reported elsewhere (Petersen et al., 1998; Tüzel et al., 2001; Saito et al., 2008). This increase of soluble solids seems to be related to an increase in soluble sugar accumulation, a reduced water content of the fruit and reduced fruit cell size causing a concentration of soluble solids (Adams and Ho, 1989;

Mitchell et al., 1991; Saito et al., 2008). Increased values of total soluble solids and acidity are an active adaptation of plants to salinity to maintain water uptake under osmotic stress conditions (Hasegawa et al., 2000).

II.4. CONCLUSIONS

Tomato, a crop plant considered moderately sensitive to salinity, may display a wide range of tolerance to salinity depending on genotype. In our study, Veracruz yielded the less and Vengador the most for all treatments. Nevertheless in regard to yield decrease percent and root/shoot ratio development, Veracruz demonstrated the highest tolerance to the salinity levels applied, followed by Puebla. The Oaxaca landrace performed the poorest with high yield decrease and was the only genotype with increasing root/shoot ratio tendency in this investigation. Indeed, dry matter was reduced by salinity stress and genotypes showed to be able to produce different dry matter quantities under influence of salinity. The fruit quality characteristics total soluble solids and pH were affected positively by salinity stress conditions. As suggested in other publications salinity stress can improve tomato fruit quality and taste. Plants can be stressed to a certain level that does not reduce yield significantly in order to increase fruit quality.

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CAPÍTULO III. GROWTH PARAMETERS AND NUTRITIONAL STATUS OF MEXICAN TOMATO LANDRACES IN RESPONSE TO SALT STRESS

III.1. INTRODUCTION

Soil salinity is an abiotic stress factor for almost all commercial crops. Soils with EC values above 4 dS m^{-1} (equal to approximately 40 mM NaCl) are considered saline and most crop plants growth will be affected negatively at this value, sensitive crops already at 2 dS m^{-1} (SSSA, 2016).

Since 1998 the worldwide agricultural land area did not increase and neither did arable land area significantly since 1992 (World Bank, 2016). Already millions of people are undernourished and under the pressure of a growing world population yield must increase sustainably per cultivated area, without harmful trade-offs related to excessive use of water, fertilizers and pesticides which will worsen the situation for ecosystems in long term (MEA, 2005). Irrigated land is at least twice as productive as rainfed land thus the irrigation of drylands is an important option to achieve food security (Munns and Tester, 2008). But water sources suitable for irrigation mostly contain salt in some extend and thereby may become the cause for a salinization process of soils or substrates if not managed in a correct manner and thereby reduce yields due to salt stress (Flowers, 1999).

As agronomic and engineering solutions are at its limits, the introduction of salt tolerant plants for cultivation is important to minimize the negative effects of saline soils on crop production (Munns and Gilliham, 2015).

With a production of 3.28 million metric tons on 87.1 thousand ha in 2013 and with 1055 million USD value of tomato exportation in 2014, the tomato is one of the most important agricultural products of Mexico (SAGARPA, 2016; FAOSTAT, 2016). Approximately 85% of the Mexican tomato cultivating area is using irrigation techniques and furthermore 46 Mexican aquifers (7% of the total) show problems related to salinity (CONAGUA, 2015; SIAP, 2016)

The reducing yield of most commercial tomato cultivars by soil salinity (EC above 2.5 dS m^{-1}) is an evident threat to the Mexican tomato growing industry, nevertheless salinity tolerant cultivars, varieties and landraces exist (Singh et al., 2012; Nouck et al., 2016, Caro et al., 1991).

Mexico as the center of the final domestication, of the modern tomato (*Solanum lycopersicum* L.) has a high, but poorly documented, diversity of native tomato landraces, known as “tomate criollo” in Mexico, which can be found in all parts of the country. These present different fruit shapes and sizes and plant characteristics, and some landraces may show agronomic tolerances to abiotic stress like salinity (Blanca et al., 2012; Lobato-Ortiz et al., 2012).

Estrada (2013) demonstrated that some native Mexican tomato varieties have elevated salinity tolerance in terms of germination, aerial and root dry matter accumulation. In addition, According to Sanjuan-Lara et al. (2015) young tomato plants of some native Mexican populations from the state of Puebla were outstanding in terms of root, leaf and shoot dry mass as well as plant height and number of leaves.

The distribution and concentration of nutriments within the plant parts can give valuable information on the capability of exclusion of Na and Cl from certain plant parts and maintenance of essential nutriments.

In this study we aimed to analyze the effect of four levels of salinity (0, 30, 60, 90 mM NaCl) on four native Mexican landraces from the states Campeche, Oaxaca, Puebla and Veracruz and one commercial cultivar of the Saladette type, Vengador (Syngenta). Evaluated variables include plant height, number of leaves and trusses as well as number of fruits, fruit weight and size and the nutrimental content of the root and the lower and upper part of plants shoot and leaves.

III.2. MATERIALS AND METHODS

The experimental design was completely randomized and comprised four native Mexican landraces, one commercial hybrid and four salinity treatments levels, 0, 30, 60 and 90 mM NaCl and 10 replications.

The plants grew in a greenhouse with drip irrigation system in the Colegio de Postgraduados Campus Montecillo in Texcoco, State of Mexico (Mexico) in the year 2015. The native landraces from the states of Campeche, Oaxaca, Puebla and Veracruz, of the types Kidney, Ribbed Kidney-Shaped, Chino Criollo (bell pepper shaped) and Citlale (star-tomato), which might be identical to *Solanum lycopersicum* var. cerasiforme (Dunal, Spooner, Anderson and Jansen), respectively and one commercial hybrid of the Roma-Saladette type, Vengador (Syngenta) were obtained from seeds sown in trays filled with peat moss based substrate and irrigated with tap water with EC of 0.4 dS m^{-1} and pH was adjusted to 6 with 0.1 N NaOH. (Jenkins, 1948; Lobato-Ortiz et al., 2012; Rodríguez et al., 2009). Twenty days after germination the young plants were irrigated with a nutrient solution of 50% prepared according to Steiner (1984). At 45 days of age Steiner solution was increased to 75% and plants were transplanted into tezontle, an inert local volcanic gravel of particle size between 1 and 20 mm, filled black polyethylene bags of 10 liters of capacity. The polyethylene bags were spaced 120 between rows and 30 between plants and plants were guided with rope to an above installed wire at 250 cm height above ground. The Steiner solution was increased to 100% with plants of 60 days of age and treatments were applicate 70 days after sowing. The concentration of 0, 30, 60 and 90 mM of NaCl was added to the 100% Steiner solution for treatment levels of 2.4, 5.4, 8.4 and 11.4 dS m^{-1}, respectively, final EC. Agrochemicals were applied as according to product instruction to assure healthy plants growth. Suckers on the plants were cut when appearing and lower leaves when drying out.

Plants were harvested 17 weeks after sowing and were divided by height into one upper and one lower part and the leaves and shoot from each part as well as the roots were dried at 65 °C for one week in a forced air drying oven (Riossa HCF-125D; Guadalajara, Jalisco, Mexico).

The harvest of fruits was realized at a full maturity stage during the time of cultivation to measure fruit weight, diameter and length. The concentration of the elements P, K, Mg, Ca, Fe, Cu, Zn, Mn, B and Na was analyzed for each part of the plant by humid digestion using sulfuric and percloric acid and with the addition of hydrogen peroxide and the use of an inductively coupled optical emission spectrometer (ICP-OES Agilent®, model 725-ES, Santa Clara, California, USA). Nitrogen concentration was analyzed by the Kjeldahl method (Kjeldahl, 1883). We digested plant material with concentrated HNO_3 and H_2O_2 to analyze Cl concentration with a spectrophotometer (Spectronic 20, Thermo Fisher, Madison, WI, USA). The concentration of the analyzed elements was calculated by plant part dry weight and the content analyzed. Data was subject to analysis of variance (ANOVA) using the GLM procedure of SAS ver. 9.3 (SAS Institute, Cary, North Carolina, USA, 2011) to detect tomato response to NaCl and mean separation was realized with Tuckey's range test. Predetermined significance level was set up with alpha equal to 0.05.

III.3. RESULTS AND DISCUSSION

The fruit number is affected by salinity depending on genotype. While Oaxaca, Vengador and Veracruz are not affected in fruit numbers by increasing salinity stress, Campeche shows significantly reduced fruit numbers at 90 mM NaCl compared to the control. Puebla shows the highest number of fruits for 30 mM NaCl and only 90 mM NaCl decreases the fruit number significantly compared to the other 30 mM NaCl (Figure III.1). The small fruited landrace Veracruz showed the highest fruit number for all treatments.

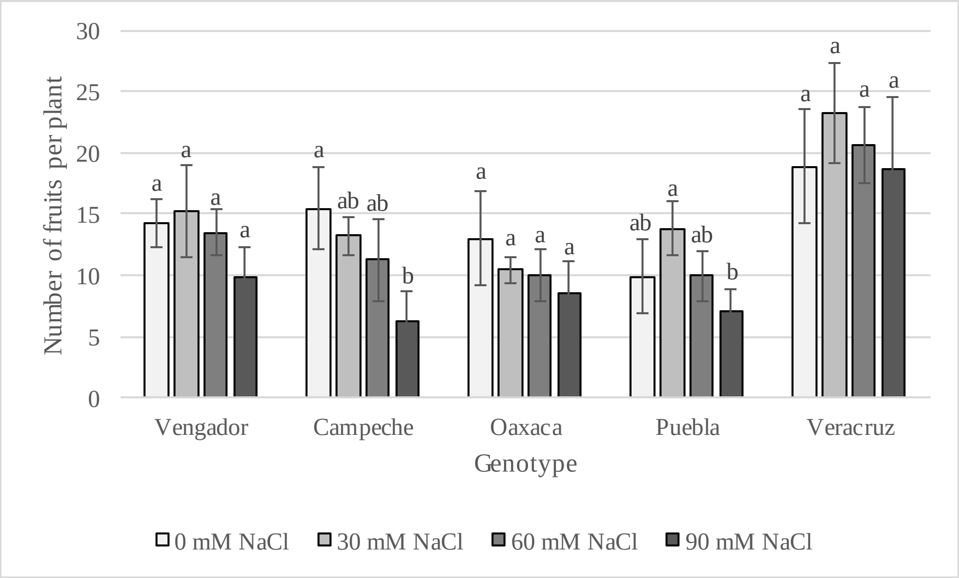

Figure III. 1. Average number of fruits per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Investigations concluded differently on salinity effects on fruit number. Ehret et al. (2013) reports significantly decreased fruit number at 6 dS m^{-1} for one cultivar and Del Amor et al. (2001) showed significantly lower fruit number for 6 and 8 dS m^{-1} compared to 4 dS m^{-1} for a cultivar, with no significant differences between 16, 36 and 66 days of exposure to salt stress. Magán et al. (2008) showed differences between cultivars and exposure time in three experiments, with one cultivar not decreasing fruit number at 154 days of cultivation time with levels of up to 7 dS m^{-1} and another cultivar decreased fruit number significantly with salinity treatments up to 5 dS m^{-1} and 183 and 266 day of growing time. The exposure to salinity, 50 mM NaCl, compared to control conditions without NaCl as well as the cultivar have significant effects on fruit number. As shown by Nouck et al. (2016) salt tolerant cultivars do not lower in fruit number due to salinity stress. Cuartero and Fernández-Muñoz (1999) stated that fruit number is more likely to reduce when salinity stress duration is exceeding four weeks and Singh et al. (2014) concludes that a high intensity of salinity stress is more likely to be responsible for reduced fruit number. Ghanem et al. (2009) reported that young tomato plants exposed to 150 mM NaCl for 10 days were able to grow until two month of age, showing a reduced number of pollen and pollen viability as well as significantly increased flower abortion, but no effects on number of flowers. Parvin et al. (2015) showed that the number fruits as well as the number of flowers per tomato plant decrease with increasing salinity stress level.

Fruit weight was negatively affected by salinity in all genotypes. Puebla displayed significantly lower fruit weight for the salinity levels 60 and 90 mM NaCl compared to the control (0 mM NaCl). Veracruz and Campeche did not show any further decrease of fruit weight when exposed to 60 and 90 mM NaCl compared to 30 mM. Instead, Oaxaca was further affected, with lower fruit weight at the 90 mM NaCl treatment and Vengador was severely affected, in the weight of the fruit, with increase of 60 mM and 90 mM in the salinity levels (Figure III. 2).

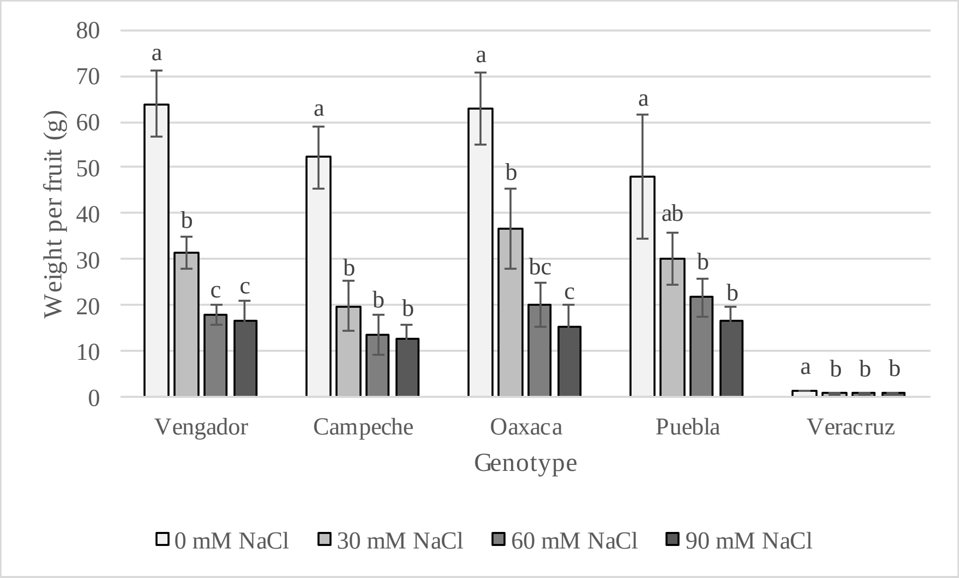

Figure III. 2. Average weight of fruits per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Nouck et al. (2016) showed a decrease in fruit weight at 50 mM NaCl for some salt sensitive cultivars. Fruit weight is negatively affected when salinity in the nutrient solution raises up to 7.8 dS m^{-1} (Magán et al 2008). The observation of this tendency is matching with those of others authors such as Del Amor et al. (2001) and Ehret et al. (2013). At high EC values, 100 and 150 mM NaCl, fruit weight does decrease compared to control, but there is no significant difference between 100 and 150 mM NaCl, as shown for a tomato local variety from Greece (Giannakoula and Ilias, 2013). Genotypes responded differently to salinity in terms of fruit weight, though in general, this variable decreased when EC increased. Salinity induced toxic accumulation of Na and Cl ions cause cell death in older leaves, and thus less carbohydrate production to support fruits. Moreover, osmotic stress in general slows carbon accumulation and affects the plants tissue expansion negatively as well as reducing cell number (Tardieu et al., 2011; Munns and Tester, 2008). A reduced water flow into fruits can be attributed to salinity stress caused by lower water potential, which reduces directly the fruit expansion rate (Johnson et al., 1992). Tomato plants under salinity stress have reduced xylem exudation flow by a factor of 17 to 20 compared to control plants, which is especially important as tomato truss receive 75% of the water and nutrient, facilitated by the xylem tissues for the first eight weeks of development (Windt et al., 2009; Kafkafi, 1991).

All genotypes decreased in fruit length at 30 mM NaCl compared to control. For Puebla only the 90 mM treatment resulted in lower fruit length compared to control. Campeche was not affected further by 60 and 90 mM treatments, while Oaxaca and Vengador show further significant lower fruit length at 60 and 90 mM NaCl compared to 30 mM. Interestingly, fruit length for the Veracruz landrace is reduced when plants are exposed to 30 and 60 mM, but the exposure to 90 mM NaCl produced similar results as the control (Figure III. 3).

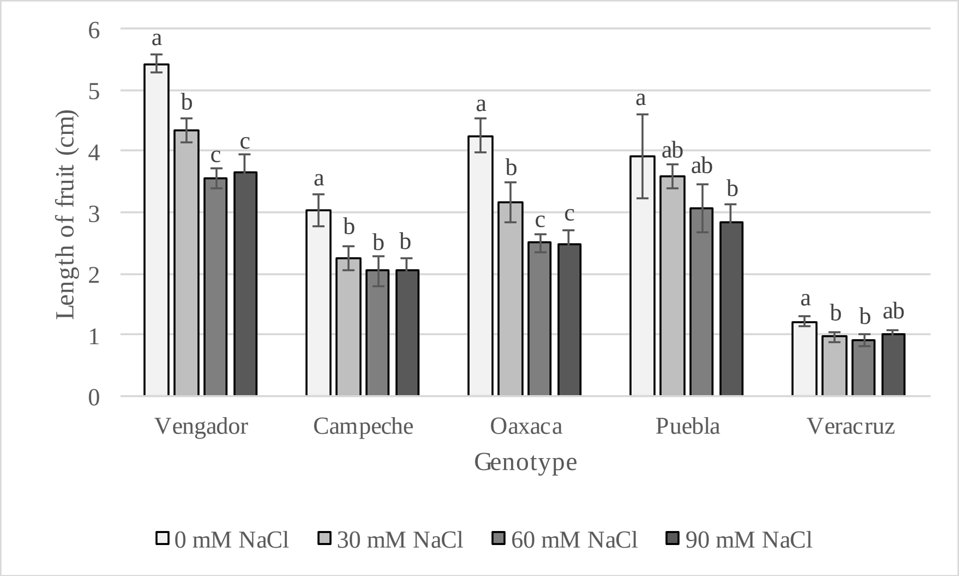

Figure III. 3. Average length of fruits per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Fruit diameter in the case of the genotypes Vengador, Campeche and Veracruz is affected by salinity in the same way as fruit length. Campeche develops fruits with lower diameter at 30, 60 and 90 mM NaCl compared to control, while Vengador reduces fruit diameter at 30 mM compared to control and again at 60 and 90 mM compared to control and 30 mM treatments. Fruit diameter for Veracruz is reduced for 30 and 60 mM compared to control but not for 90 mM treatments. The Oaxaca landrace reduced fruit diameter at 60 and 90 mM of NaCl compared to control and the Puebla landrace reduces fruit diameter at elevated salt treatments compared to control (Figure III. 4).

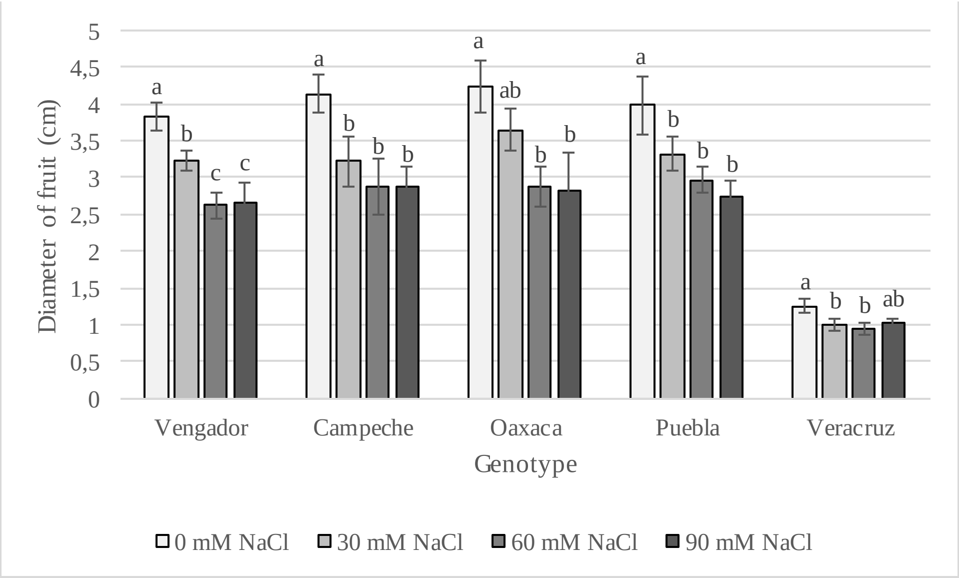

Figure III. 4. Average diameter of fruits per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

The changes in fruit size, length and diameter, can be related to the reduced fruit weight. Fruit size has a decreasing tendency as salinity stress increases. The fruit length and diameter of the cultivar Saladette and the landraces Campeche and Veracruz correlated very well to fruit weight and fruit length. The difference between decreased fruit length and diameter at each salinity level is only 4% or less, except for Puebla at the 30 mM NaCl treatment, while in the case of Veracruz even less than 1%. These genotypes present a more or less round shape. The Oaxaca landrace with its irregularly flat and ribbed fruit shape is more affected by salinity in fruit length than diameter. While fruit length for Oaxaca is decreasing by 26%, 41% and 42%, fruit diameter is only decreasing by 14%, 32% and 33% for the treatments 30, 60 and 90 mM NaCl, respectively. To our knowledge there is no investigation on effects of salinity on fruit size of Mexican landraces.

Saeed et al. (2008) showed reduced fruit length and diameter in response to salinity stress of 10 and 15 dS m^{-1} for 5 cultivars with the decline in length and diameter being less severe in salt tolerant cultivars. A reduced fruit length and diameter, which correlates with reduced fruit cell and fruit weight has been clearly documented in response to salinity stress (Parvin et al., 2015; Saito et al., 2006).

The induced salinity stress of the treatments did not decrease the number of trusses for the landraces Veracruz and Campeche. The Oaxaca landrace developed lower number of trusses at 90 mM NaCl compared to the control and 30 mM NaCl treatment, whereas the Puebla landrace only showed lower truss formation at the 90 mM treatment, in comparison to the control. Vengador was the most negatively affected genotype with lower truss number at the 60 and 90 mM treatments compared to control and 30 mM (Figure III. 5).

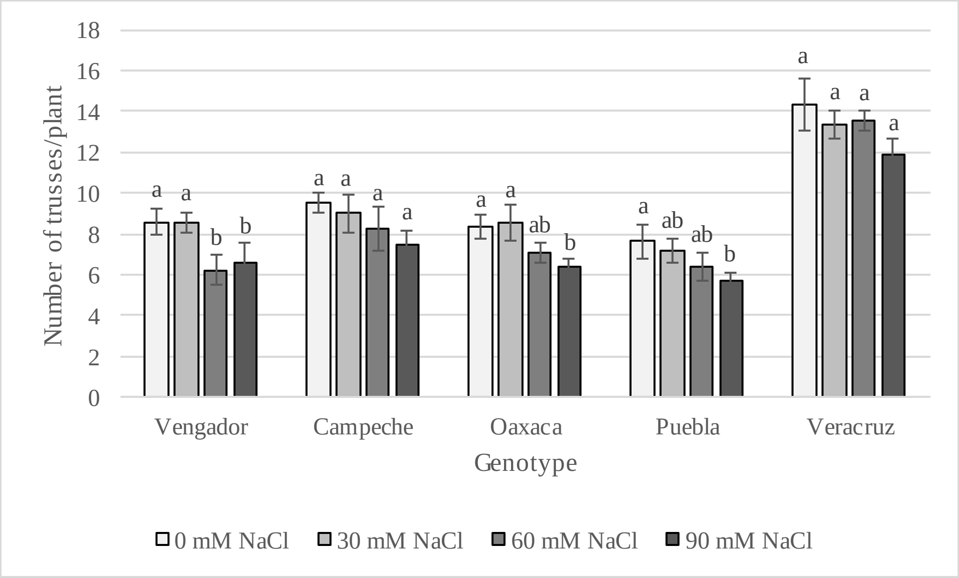

Figure III. 5. Number of trusses per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

NaCl treatments of 10 and 15 dS m^{-1} reduced number of trusses for salinity tolerant and non-tolerant cultivars compared to control (Saeed et al., 2008). Parvin et al. (2015) showed a decreasing tendency of trusses for one tomato cultivar with increasing salinity stress. Liu et al. (2014) showed for three cherry tomato cultivars that the number of trusses have a decreasing tendency with increasing salinity concentrations.

Salinity treatments differentially affected plant height in the five tomato genotypes evaluated. Vengador developed less height with the 60 and 90 mM MaCl treatments compared to control and 30 mM NaCl, while Campeche showed less height for the 60 and 90 mM NaCl treatments compared to control. Oaxaca and the Puebla landraces displayed decreased heights when exposed to 60 and 90 mM NaCl, in comparison to the control. In Veracruz plants, salinity significantly decreased height at the 30, 60 and 90 mM NaCl (Figure III. 6).

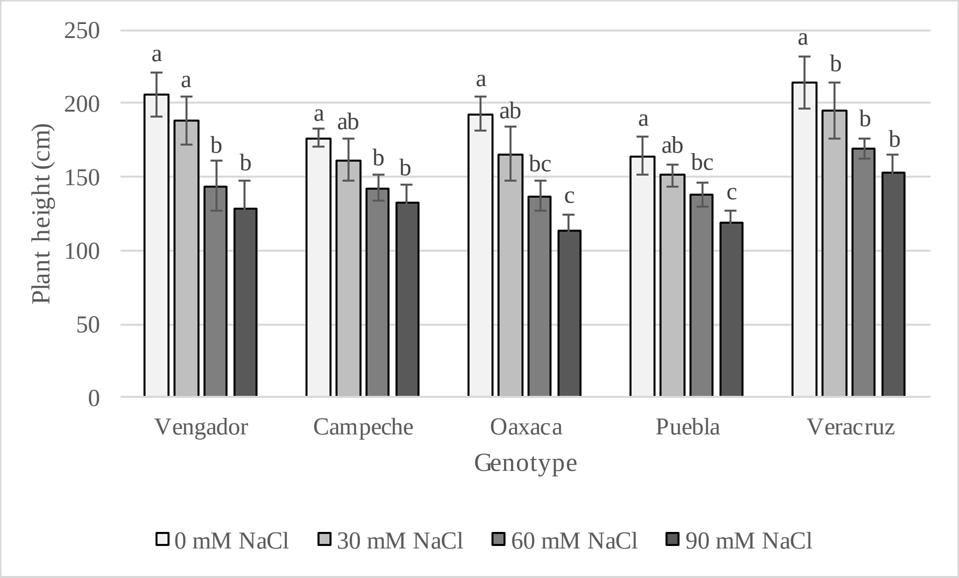

Figure III. 6. Average plant height of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

In the genotypes Vengador, Campeche and Oaxaca, leaf number displayed a similar response to plant height. Indeed, in all five tomato genotypes evaluated, the lowest number of leaves per plant was observed in plants exposed to 90 mM NaCl, though Puebla plants were the most affected (Figure III. 7). Instead, Veracruz displayed the lowest reduction respect to this variable, which further demonstrates the higher salt-tolerance level of this landrace.

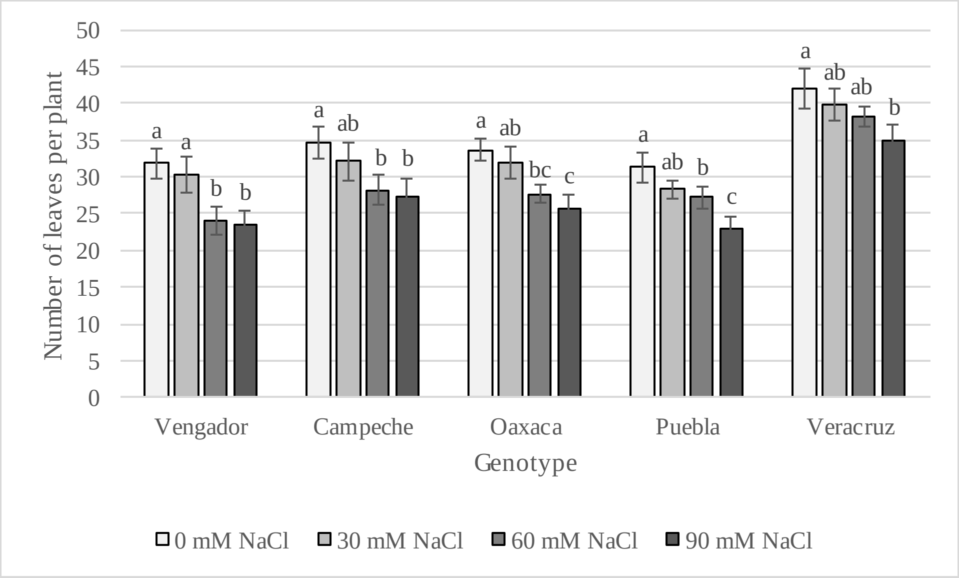

Figure III. 7. Average number of leaves per plant of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Romero-Aranda et al. (2001) also observed significant reduction of tomato plant height when exposed to 35 and 70 mM NaCl, while a significant reduction on leaf number was appreciated at 70 mM. Otzekin and Tuzel (2011) reported decreased plant height and leaf number for 33 genotypes grown for 10 days at 200 mM NaCl but percentage of decreased height compared to control without NaCl varied widely among genotypes. An investigation with 48 Mexican native tomato lines showed a decreasing tendency for plant height and leaf number for young tomato plants treated with nutrient solutions of 4 to 12 dS m^{-1}, with some lines being more tolerant than others (Sanjuan-Lara et al., 2015). The excessive uptake of Na and Cl ions due to salinity stress builds up toxic concentrations of these ions in older tomato plant leaves and cause cell death, leading to entire leaves drying out and falling of the plant and thereby reducing leaf number (Munns and Tester, 2008). Abiotic stress factors, like salinity, have major and wide spread effects on the plants phytohormone system responsible for the mediation of growth responses to this stress. Phytohormones are then produced by plants in order to overcome and survive stressful conditions, rendering reduced growth since resources are used elsewhere (Fahad et al., 2015; Peleg and Blumwald, 2011; Skirycz and Inzé, 2010) This provokes lowered plant height and leaf number.

Table III. 1. Effect of NaCl applied in the nutrient solution of five tomato genotypes on the number of fruits, weight of fruit, length of fruit, diameter of fruit, number of trusses, height of plant and number of leaves. Values are means of ten replicates. Distinct letter after means in each column and source of variation indicate significant differences among treatments.

Treatment	Number of fruits	Weight of fruit (g)	Length of fruit (cm)	Diameter of fruit (cm)	Number of trusses	Height of plant (cm)	Number of leaves
				Genotype			
Vengador	13.194 b	33.723 a	4.2902 a	3.1204 a	7.5556 c	168.278 ab	27.6111 c
Campeche	11.727 b	25.701 b	2.373 c	3.3188 a	8.6364 b	154.455 bc	30.8182 b
Oaxaca	10.394 b	32.543 ab	3.0582 b	3.3527 a	7.5152 c	149.303 c	29.3939 bc
Puebla	10.179 b	28.728 ab	3.3385 b	3.2344 a	6.7179 c	142.487 c	27.3333 c
Veracruz	20.355 a	1.067 c	1.0345 d	1.0635 b	13.3548 a	185.29 a	38.9677 a
				NaCl concentration			
0 mM	14.311 a	45.698 a	3.5972 a	3.4818 a	9.7111 a	190.889 a	34.6444 a
30 mM	15.186 a	23.868 b	2.9075 b	2.9024 b	9.2326 a	171.628 b	32.2326 b
60 mM	12.775 ab	15.624 c	2.4948 c	2.508 c	8.1 b	145.05 c	28.725 c
90 mM	9.659 b	13.224 c	2.4832 c	2.4955 c	7.3409 b	127.523 d	26.3864 d
				P values from ANOVA			
Genotype	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
NaCl concentration	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interaction	0.7643	<0.0001	0.0008	0.1252	0.8386	0.5245	0.8976

The nutritional status of the roots depends on treatments and genotype. While for each genotype no significant differences between treatments could be found in the case of Mg, Fe, Cu, Zn, Mn and Cl, significant difference for the concentration of Na in the roots is evident for all genotypes. The concentration of N, P, K, Ca and B was effected significantly by salinity in some genotypes, but not all. K and Ca concentration was decreased significantly by 60 and 90 mM NaCl compared to control. Concentrations of Na increased with increasing application of NaCl concentration. Oaxaca had significantly higher K concentration compared to Campeche and Puebla, while Vengador had higher Ca concentration compared to Campeche and Veracruz. The cultivar Vengador accumulated by far the highest concentration of Na in the root followed by Veracruz and Campeche the lowest, with only 40% of the concentration found in Vengador. The Cl concentration was lowest in Puebla compared to Vengador, Oaxaca and Veracruz. We found significant effects of the genotype and NaCl concentration for the K, Ca and Na concentration and an interaction was significant for N, P, K and Mg. The effect of salinity stress on N, Fe, Cu, B and Cl was effected significantly by the genotypes (Table III. 2)

Table III. 2. Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the root tissue of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments

	Concentration of element in ppm											
Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
0 mM	12775 a	5372.8 a	1924.8 a	17107 a	7225.4 a	5334.2 a	107.27 a	147.57 a	2011.6 a	36.189 a	2788.4 b	415.85 a
30 mM	12250 a	4271.3 a	2259.8 a	15718 a	7411.4 a	6721 a	111.06 a	112.71 a	1649.9 a	45.038 a	10146 ab	460.4 a
60 mM	14350 a	6590.6 a	1156 a	14144 a	6255.9 a	6663.1 a	146.7 a	142.37 a	2890.8 a	36.644 a	11031 ab	336.64 a
90 mM	10150 a	5062.7 a	1627 a	10661 a	6409.3 a	7213.3 a	104.88 a	111.74 a	1640.7 a	32.618 a	17527 a	470.3 a
0 mM	11725 a	5663.4 a	1419.9 a	13805 a	7424.9 a	8223 a	125.43 a	142.41 a	2502.5 a	26.597 a	2100.3 c	361.39 a
30 mM	11025 a	4726.7 a	1061.6 a	12002 a	8825.2 a	10273 a	89.443 a	111.12 a	2214.8 a	22.289 a	3836.4 bc	297.03 a
60 mM	16275 a	5585.7 a	943.3 a	11153 a	7961.9 a	8959.4 a	99.062 a	130.84 a	2502.2 a	21.397 a	5818.8 ab	396.05 a
90 mM	16700 a	6194.4 a	882.07 a	10882 a	6252.5 a	7276.6 a	107.59 a	149.35 a	2672.3 a	23.3 a	6929.3 a	326.74 a
0 mM	13475 a	3909.5 a	4060.9 a	15429 a	8127.6 a	6354.7 a	82.513 a	93.242 a	1022.8 a	43.32 a	3567.3 b	378.09 a
30 mM	16450 a	5990.5 a	2129.2 b	12136 a	7239.3 a	5831.2 a	98.032 a	133.4 a	2469.4 a	25.668 a	7834.3 a	460.4 a
60 mM	14700 a	6276.9 a	1189.1 b	12346 a	7067.3 a	5982.6 a	100.23 a	130.23 a	2653.7 a	25.58 a	6273.7 ab	381.19 a
90 mM	11200 a	4981.2 a	1385.3 b	11134 a	7669.2 a	7957 a	86.127 a	101.92 a	1997.5 a	25.521 a	9073.6 a	336.64 a
0 mM	24325 a	7615.9 a	1762.7 a	17216 a	6216.9 a	5910.9 a	96.131 a	145.68 a	3214.3 a	24.39 a	1644 b	257.43 a
30 mM	15750 ab	4596.3 a	1296.9 a	12989 b	6998.1 a	8100.2 a	74.558 a	107.84 a	2366.3 a	24.743 a	3559.7 ab	326.74 a
60 mM	11200 b	4277.4 a	1049.4 a	11374 b	7340.8 a	7881.7 a	70.625 a	95.209 a	1973.9 a	19.887 a	5511.5 ab	258.89 a
90 mM	15925 ab	5263.2 a	1162 a	13276 b	6124.2 a	5958.8 a	85.472 a	122.86 a	2347.7 a	28.017 a	8466.1 a	316.84 a
0 mM	9550 a	3312.9 b	1711.3 a	10845 a	8083.1 a	9899.2 a	64.068 a	75.967 a	1294.1 a	15.288 b	2258.6 c	477.23 a
30 mM	11988 a	4062.1 ab	1477.2 a	11546 a	7279 a	7843.4 a	79.011 a	105.43 a	2025.9 a	22.97 ab	4735.1 bc	351.49 a
60 mM	15050 a	5955.1 a	1939.1 a	11668 a	6336.8 a	5698.4 a	88.91 a	119.59 a	3208.1 a	23.149 ab	6508.3 b	326.74 a
90 mM	14875 a	5155.8 ab	1693.4 a	11713 a	6478.9 a	6818.6 a	97.971 a	132.65 a	1937 a	30.891 a	16541 a	401 a

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	12381 b	5324.3 a	1741.9 ab	14408 a	6825.5 a	6482.9 b	117.5 a	128.6 a	2048.2 a	37.6 a	10373 a	420.8 a
Campeche	13931 ab	5542.6 a	1076.7 b	11960 b	7616.1 a	8683.1 a	105.4 ab	133.4 a	2473 a	23.4 b	4671 b	345.3 ab
Oaxaca	13956 ab	5289.5 a	2191.1 a	12761 ab	7525.9 a	6531.4 b	91.7 ab	114.7 a	2035.8 a	30 ab	6687 b	389.1 a
Puebla	16800 a	5438.2 a	1317.8 b	13714 ab	6670 a	6962.9 ab	81.7 b	117.9 a	2475.6 a	24.3 b	4795 b	290 b
Veracruz	12866 ab	4621.4 a	1705.2 ab	11443 b	7044.4 a	7564.9 ab	82.5 b	108.4 a	2116.3 a	23.1 b	7511 ab	389.1 a
0 mM	14370 a	5174.9 a	2175.9 a	14880.2 a	7415.6 a	7144.4 a	95.1 a	120.97 a	2009.1 a	29.2 a	2472 c	378 a
30 mM	13493 a	4729.4 a	1644.9 ab	12878.1 ab	7550.6 a	7753.8 a	90.4 a	114.1 a	2145.3 a	28.1 a	6022 b	379.2 a
60 mM	14315 a	5737.1 a	1255.4 b	12137.2 b	6992.5 a	7037 a	101.1 a	123.7 a	2645.8 a	25.3 a	7029 b	339.9 a
90 mM	13770 a	5331.5 a	1350 b	11533.2 b	6586.8 a	7044.9 a	96.4 a	123.7 a	2119 a	28.1 a	11707 a	370.3 a
						P value from ANOVA						
Genotype	0.0437	0.5094	0.0004	0.0058	0.1528	0.0173	0.0015	0.258	0.4527	0.0004	<0.0001	0.0038
NaCl concentration	0.8941	0.257	0.0004	0.0003	0.0807	0.6344	0.6795	0.8025	0.1493	0.6734	<0.0001	0.5471
Interaction	0.0029	0.0319	0.0081	0.1674	0.03825	0.0757	0.2822	0.1079	0.1073	0.1754	0.0505	0.2435

The concentration of NO_3^- was reported to decline in tomato roots during long salinity treatments (10 weeks) for salinity sensitive genotypes, while more tolerant genotypes may maintain the concentration (Pérez-Alfocea et al., 1993). Cruz y Cuartero (1990) reported a decline in root K and Ca concentration for some genotypes and that salt tolerant ones do not decline in concentration. Depending on genotype and salt resistance K and Ca tomato root concentration may be maintained or decrease slightly (Cuartero and Fernández-Muñoz, 1999). This might indicate a certain salinity stress resistance for the investigated genotypes. The relationship between P concentration in plant tissue and salinity is rather complex and depends on many factors like salinity concentration and plant species and cultivar (Grattan and Grieve, 1992; Grattan and Grieve, 1999). Salinity stress normally decreases P concentration in tomato plants (Kaya et al., 2001).

There is a significant difference between species and cultivars, grown under the same experimental conditions, in regard to the B uptake and tomato cultivars efficient and ineffient in B uptake are identified, with an inefficient cultivar not being capable of translocating B from the root to the shoot and thus accumulating higher B concentrations than an efficient cultivar (Brown and Jones, 1971; Bellaloui and Brown, 1998).

The increase of the concentration of Na in tomato roots due to salinity stress exposure has been reported elsewhere with a considerable variation of concentrations reported depending on genotype and salinity stress intensity (Alian et al., 2000; Pérez-Alfocea et al., 1993; Tuna et al., 2007; Manaa et al., 2011). Na enters the root mainly passively, through non selective cation channels, and possibly by other transporters and is pumped back out from the root by the plasma membrane trough Na/H antiporters in a certain extend. In further steps, a compartmentation of Na in vacuoles by tonoplast Na/H antiporters takes place or the ion is further transported to the shoot. It is suggested that a higher capability of storing Na in vacuoles increases salt tolerance by reduced Na in the cytosol (Munns and Tester, 2008). While Pérez-Alfocea et al. (1993) reported an increased Cl concentration in tomato roots due to salinity stress after 3 and 10 weeks of treatment for different cultivars and some landraces, such responses could be observed in our investigation.

Na concentration in the root and in the shoot are directly correlated. Once Na passes into the shoot xylem flow it stays in the shoot because most plants have limited capability to transport Na via phloem back to the root and thereby Na concentration in shoot is mainly determined in the root by processes of Na delivery into the shoot xylem flow (Munns and Tester, 2008).

Stem nutrimental status was evaluated separately for the upper and lower half, divided by height. N and Mg concentration was not affected by salinity stress for any of the genotypes for any of the two parts of the stem. We observed differences in the nutrient status of the lower and upper part for each genotype as affected by NaCl and for treatments.

Oaxaca showed and elevated P concentration in the lower part of the stem due to NaCl stress. Na concentration showed an increasing tendency for Vengador, Campeche and Oaxaca due to salinity stress. We found significant effects of the genotype on N, P, K, Cu, Zn, B and Na concentration under the effect of NaCl treatments. Furthermore the treatment NaCl concentration showed significant effects on P, K, Ca, Cu, Zn, Mn, NA and Cl concentration. Interactions could not be found. Campeche had the highest Na concentration with 71% higher concentration than Veracruz which showed the lowest. K concentration in Vengador was lowest of all genotypes under influence of treatments and highest in Oaxaca. Veracruz showed the highest P concentration and Campeche the lowest, almost 43% less, but Ca concentration was highest in Vengador and lowest in Veracruz. The upper part of the stem of each genotype was affected very differently by the salinity stress in regard to element concentration but N, P and Mg concentration were not affected. Na concentration increased for Campeche due to salinity stress, but difference was only significant for 60 mM compared to control, and Oaxaca showed elevated concentration at salinity stress treatments compared to the control. An increasing Cl tendency for Veracruz was only significant for the 60 mM treatment compared to control. The genotypes under influence of salinity stress showed a significant response for N, P, K, Ca, Mg, Zn, Mn, B and Na concentration. The treatment NaCl concentration showed significant responses for K, Zn, Mn, Na and Cl concentration and we found interactions for N, K and Fe concentrations. Vengador showed the highest Na concentration, 118% higher than the concentration found in Veracruz with the lowest concentration observed.

Kaya et al. (2001) reported a decreasing P concentration in tomato tissue due to salinity stress. The effect of salinity reducing K concentration in tomato stems was also described by Taffouo et al. (2010) for several cultivars. The increased Ca concentration due to increased salinity stress in our investigation is in contrast to observations by other authors as a response to salinity stress (Taffouo et al., 2010). Our observations are in contrast to one investigation showing that a decrease of Cu and Zn concentration in stems of six tomato cultivars, one salt-tolerant, one moderately tolerant and four salt-sensitive, with increasing salinity stress conditions, 50, 100 and 200 mM NaCl, was depending in magnitude to the salt resistance of the cultivar (Nouck et al., 2016). Nonetheless, Maas et al. (1972) showed an increase in tomato shoot Zn concentration due to salinity stress as well as elevated Mn concentration. Manaa et al. (2011) demonstrated significant differences in the Na accumulation in stems of tomato plantlets exposed to NaCl stress.

Table III. 3. . Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the lower stem tissue of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments

		Concentration of element in ppm											
Genotype	Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
Vengador	0 mM	12075 a	5330 a	8693.5 a	7523.8 a	6304.3 a	186.22 a	203.94 a	55.098 a	138.2 a	31.209 a	7496.7 b	498.88 a
	30 mM	13825 a	4520.8 a	7271.3 a	9221.5 a	7967.5 a	161.67 a	463.01 a	63.968 a	187.8 a	43.883 a	17840 ab	515.51 a
	60 mM	13388 a	4506.3 a	6625.3 a	9665.5 a	8880.1 a	421.4 a	535.69 a	55.983 a	223.06 a	41.66 a	21235 a	307.64 a
	90 mM	13825 a	4740.7 a	7134.3 a	6087.2 a	6342.5 a	110.98 a	331.9 a	45.645 a	165.35 a	42.668 a	25345 a	631.91 a
Campeche	0 mM	17500 a	4004.9 a	14954 a	5732 a	5198.7 a	129.93 a	157.36 a	29.298 a	97.562 a	27.877 a	12458 c	207.98 a
	30 mM	16100 a	3362 a	10215 ab	7360.1 a	7635.2 a	110.69 a	233.42 a	32.32 a	132.79 a	31.227 a	23015 bc	598.65 a
	60 mM	13650 a	3366.4 a	8183.8 b	10114 a	9392.7 a	152.46 a	408.9 a	50.45 a	261.32 a	39.574 a	43175 ab	324.27 a
	90 mM	14875 a	3566 a	9486.4 b	6352.7 a	6012.2 a	137.64 a	344.98 a	27.956 a	139.32 a	38.721 a	30857 a	598.65 a
Oaxaca	0 mM	16013 a	4721.6 a	14572 a	6716.4 a	5623.6 a	136.95 a	104.98 b	40.23 a	69.931 a	29.469 a	8212.8 b	216.18 a
	30 mM	16800 a	3596.2 b	11705 a	5959 a	6059.3 a	90.657 a	194.31 ab	39.104 a	118.12 a	39.504 a	31428 a	382.47 a
	60 mM	16419 a	3655.7 b	11532 a	7599.3 a	6939.7 a	96.238 a	247.76 a	37.213 a	137.73 a	34.395 a	28236 a	440.67 a
	90 mM	21019 a	3790.6 b	11727 a	4685.1 a	4375.2 a	62.393 a	160.73 ab	24.666 a	104.48 a	25.12 a	27402 a	340.9 a
Puebla	0 mM	17500 a	4154.7 a	12966 a	6984.9 a	4548.2 a	80.734 a	132.88 a	30.664 a	114.87 a	28.175 a	8888.9 a	116.4 a
	30 mM	16713 a	3575.6 a	10111 a	6288 a	4982.3 a	106.89 a	213.76 a	27.286 a	124.32 a	30.977 a	23870 a	473.93 a
	60 mM	17675 a	4574.1 a	11099 a	7443.4 a	6299.7 a	144.34 a	267.69 a	51.142 a	163.07 a	30.948 a	28801 a	631.91 a
	90 mM	17063 a	4084 a	10443 a	6064.8 a	5199.6 a	94.086 a	386.21 a	35.711 a	122.23 a	34.123 a	26748 a	731.69 a
Veracruz	0 mM	17150 a	5905.6 a	8613.1 a	7408.7 a	6499.1 a	131.19 a	229.16 a	42.491 a	139.25 a	44.6 a	10564 a	424.04 a
	30 mM	15575 a	4636.5 a	7200.1 ab	5379.7 a	4040.2 a	107.84 a	199.68 a	51.644 a	116.44 a	31.908 a	14699 a	299.49 a
	60 mM	14963 a	4703.6 a	6351.9 b	6473.5 a	4230.9 a	954.74 a	243.56 a	58.946 a	153.96 a	39.607 a	19595 a	366.46 a
	90 mM	16363 a	5256.8 a	8591 a	5461.8 a	4373.9 a	117.48 a	169.51 a	44.722 a	135.74 a	40.881 a	19057 a	390.79 a

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	13278 b	4774.5 a	7431.1 b	8124.5 a	7374 a	220.1 a	383.6 a	55.2 a	178.6 a	39.855 a	17979 bc	488.5 a
Campeche	15532 ab	3574.8 b	10710 a	7389.6 a	7060 a	132.7 a	286.2 ab	35 b	157.8 ab	34.4 a	27376 a	432.4 a
Oaxaca	17563 a	3941 b	12384 a	6695.3 a	5749 a	96.6 a	177 b	35.3 b	107.6 b	32.1 a	23820 ab	345.1 a
Puebla	17238 a	4097.1 b	11155 a	6240 a	5257 a	106.5 a	250.1 ab	36.2 b	131.1 ab	31.1 a	22077 abc	488.5 a
Veracruz	16013 a	5125.6 a	7689 b	6180.9 a	4786 a	327.8 a	210.5 ab	49.5 ab	136.4 ab	39.3 a	15978 c	370.2 a
						NaCl concentration						
0 mM	16048 a	4823.4 a	11960 a	6873.2 ab	5634 a	133 a	165.67 b	39.6 ab	112 b	32.3 a	9524 b	292.7 b
30 mM	15803 a	3938.2 b	9300.4 b	6841.7 ab	6136.9 a	115.5 a	340.7 ab	42.9 ab	135.9 ab	35.5 a	22170 a	454 ab
60 mM	15219 a	4161.2 b	8758.3 b	8259 a	7148.6 a	353.8 a	260.8 a	50.8 a	187.8 a	37.2 a	28208 a	414.2 ab
90 mM	16629 a	4287.6 ab	9476.3 b	5730.3 b	5260.7 a	104.5 a	278.7 ab	35.7 b	133.4 ab	36.3 a	25882 a	538.8 a
						P value from ANOVA						
Genotype	0.0001	<0.0001	<0.0001	0.1347	0.0597	0.2803	0.0356	0.001	0.0617	0.0368	0.0009	0.3734
NaCl concentration	0.3924	0.0006	<0.0001	0.0186	0.2033	0.0759	0.0446	0.0356	0.0089	0.4093	<0.0001	0.0284
Interaction	0.291	0.6849	0.2469	0.7835	0.8671	0.3991	0.7937	0.7698	0.8685	0.2918	0.1703	0.1999

Table III. 4. Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the upper stem tissue of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments

		Concentration of element in ppm											
Genotype	Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
Vengador	0 mM	13213 a	4122 a	13458 a	6341.9 a	6640.9 a	117.63 a	191.76 a	27.049 a	113.26 a	35.139 a	24574 a	440.67 a
	30 mM	14788 a	4259.3 a	13223 a	7174.3 a	7170.3 a	1277.1 a	174.24 a	41.633 a	160.14 a	37.457 a	27746 a	457.3 a
	60 mM	13825 a	3309.4 a	12137 a	7722.9 a	8536.7 a	89.424 a	253.25 a	36.505 a	185.82 a	45.01 a	48281 a	440.67 a
	90 mM	16100 a	3667.4 a	10377 a	8767 a	7833.7 a	117.44 a	637.55 a	42.545 a	220.03 a	53.102 a	61985 a	498.88 a
Campeche	0 mM	17850 a	3941.9 a	12938 a	3917.3 b	3881.1 a	70.082 a	39.049 b	11.675 b	69.752 b	18.945 b	7885.7 b	374.16 a
	30 mM	16170 a	3875.5 a	11331 a	5157.9 ab	5819.8 a	89.475 a	140.94 ab	23.036 a	93.055 ab	24.435 ab	14654 b	282.7 a
	60 mM	16363 a	4258.5 a	10002 a	4748 ab	4455.4 a	141.87 b	90.968 b	26.919 a	95.139 ab	24.887 ab	18461 b	340.9 a
	90 mM	16100 a	3497.5 a	9787.2 a	5709.3 a	5746.1 a	77.567 a	205.85 a	30.221 a	140.65 a	31.772 a	35832 a	390.79 a
Oaxaca	0 mM	17500 a	4248.7 a	21913 a	5341.1 a	4820.8 a	61.686 a	43.528 b	15.376 b	38.888 b	21.583 a	6993.8 b	565.39 a
	30 mM	15750 a	3530.1 a	11360 b	4451 a	4099.1 a	58.434 a	76.881 ab	20.11 ab	90.185 ab	26.168 a	24660 a	399.16 a
	60 mM	18550 a	3754.8 a	15977 ab	7759.1 a	6614.3 a	130.63 a	111.43 ab	25.543 a	131.03 a	42.695 a	31057 a	565.39 a
	90 mM	18550 a	3409.1 a	12691 b	5931.9 a	6316.6 a	54.16 a	151.51 a	23.918 a	138.48 a	30.126 a	27173 a	207.86 a
Puebla	0 mM	17850 a	3313.3 a	13536 a	5335.2 a	4795.7 a	53.997 a	119.42 a	29.367 a	99.527 a	28.141 a	18291 a	274.38 a
	30 mM	17500 a	3127.7 a	11215 a	5298.1 a	4669 a	82.031 a	68.05 a	29.655 a	113.29 a	24.302 a	24134 a	257.75 a
	60 mM	16975 a	3592.3 a	12148 a	6882.9 a	6946.4 a	82.285 a	141.37 a	28.738 a	123.8 a	30.044 a	20890 a	448.99 a
	90 mM	14700 a	3209.8 a	9779 a	6612.7 a	6296.3 a	83.602 a	232.01 a	42.032 a	157.47 a	31.726 a	36520 a	407.42 a
Veracruz	0 mM	14875 a	4602.2 a	13982 a	4299.9 a	4354.6 a	119.23 a	66.918 a	20.529 a	69.113 a	27.069 a	13081 a	174.61 b
	30 mM	19075 a	4367.9 a	12658 a	6504.5 a	5946.3 a	80.948 a	186.35 a	32.462 a	125.62 a	34.571 a	25129 a	465.62 ab
	60 mM	17332 a	4675.6 a	13666 a	4088.3 a	3982.2 a	183.5 a	70.073 a	21.264 a	89.78 a	29.543 a	17139 a	673.49 a
	90 mM	22225 a	4680.1 a	12816 a	4303.9 a	3954.3 a	112.88 a	69.944 a	22.954 a	94.302 a	29.577 a	19208 a	390.79 ab

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	14481 b	3839.5 b	12299 b	7501.5 a	7545.4 a	400.4 a	314.2 a	36.9 a	169.8 a	42.7 a	40647 a	459.4 a
Campeche	16621 ab	3893.4 b	11014 b	4883.1 b	4975.6 b	94.7 a	119.2 a	23 c	99.7 b	25 b	19208 b	347.1 a
Oaxaca	17588 a	3735.7 ba	15485 a	5870.8 ab	5462.7 ab	76.2 a	95.8 a	21.2 c	99.7 b	30.1 ab	22471 b	396.6 a
Puebla	16756 ab	3310.8 c	11670 b	6032.2 ab	5676.8 ab	75.5 a	140.2 a	32.5 ab	123.5 ab	28.6 ab	24959 b	347.1 a
Veracruz	18377 a	4581.4 a	13281 ab	4799.1 b	4559.4 b	124.1 a	98.3 a	24.3 bc	94.7 b	30.2 ab	18639 b	426.1 a
						NaCl concentration						
0 mM	16258 a	4045.6 a	15165 a	5047.1 a	4898.6 a	84.5 a	92.13 a	20.8 b	78.1 b	26.2 a	14165 c	365.8 a
30 mM	16657 a	3832.1 a	11958 b	5717.1 a	5540.9 a	317.6 a	129.29 a	29.4 a	116.5 ab	29.4 a	23265 bc	342.2 a
60 mM	16609 a	3918 a	12786 b	6240.2 a	6029.4 a	125.5 a	133.4 a	27.8 ab	125.1 ab	34.4 a	27166 ab	493.9 a
90 mM	17535 a	3692 a	11090 b	6265 a	6107 a	89.1 a	259.4 a	32.3 a	150.2 ab	35.3 a	36144 a	379.2 a
						P value from ANOVA						
Genotype	0.0029	<0.0001	<0.0001	0.0101	0.0044	0.0931	0.0835	<0.0001	0.0027	0.0127	<0.0001	0.4191
NaCl concentration	0.5065	0.1601	<0.0001	0.3015	0.302	0.1874	0.1727	0.0006	0.0029	0.1577	<0.0001	0.0834
Interaction	0.0562	0.1402	0.0204	0.7024	0.7153	0.0486	0.8439	0.2983	0.9117	0.9046	0.0634	0.0705

The different genotypes showed various responses to the treatments in regard to the nutrient concentration in the lower part of the leaves. Vengador was the only one with reduced N concentration as a response to 60 and 90 mM NaCl. Oaxaca increased P concentration in response to salinity stress. Vengador and Puebla had decreased K concentration due to salinity stress. Na concentration had an increasing tendency in all genotypes as NaCl concentration increased. The effect of genotype was significant for the concentration of P, K, Ca, Mg, Cu, Mn, B and Na and the effect of NaCl concentration for the concentration of N, K, Ca, Mg, Cu, Zn, B, Na and Cl. Interaction were found for K, and B concentration. Oaxaca had the lowest P concentration but the highest K concentration. K concentration decreased for genotypes with increasing NaCl concentration. Cu and Zn concentration were increased by NaCl stress. Vengador had the highest Na concentration and Puebla the lowest. For NaCl concentration the Na concentration increased with increasing salinity stress.

The response of the genotypes to the treatments resulted in unique nutritional status of the upper parts of the leaves. Ca concentration decreased for Vengador and Campeche as salinity stress increased. All genotypes showed an increasing tendency of Na as NaCl concentration was increased. The genotype had significant effects on P, K, Ca, Zn, Mn, B and Cl concentration while the NaCl concentration did so for N, P, Ca, Cu, Zn, B, Na and Cl concentrations. The concentrations of K, Mn and B were affected by interactions as well. The K concentration in Vengador was lowest and highest in Oaxaca, with 53% higher concentration in Oaxaca compared to Vengador. Ca concentration was highest in Campeche and lowest in Vengador. Veracruz showed the lowest Na concentration and Campeche the highest while Cl concentration was the lowest in Campeche and highest in Puebla. There is an increasing tendency of Na and Cl concentration with increasing NaCl concentration but in the case of Cl significant difference was only found for 30 mM compared to 90 mM.

Amjad et al. (2014) reported that the exposure to 7.5 mM and 15 mM NaCl showed a decreasing tendency of N, P, Ca and Mg, and increasing tendency of Na concentration in leaves with higher concentrations of macronutrients in the salt-tolerant cultivar, compared to the salt-sensitive one. In addition, a higher Na concentrations in the salt-sensitive cultivar compared to the tolerant one was also observed. Reduced N, Ca and K concentrations in the leaves compared to control was also found in one tomato cultivar under 75 mM NaCl treatment (Tuna et al., 2007). Significant differences in the Na accumulation of leaves was also reported by Manaa et al. (2011) in tomato plantlets exposed to 200 mM NaCl. Younger plants of a tomato cultivar exposed to 30 and 60 mM NaCl for 14 days, did not show significantly decreased N, P, K, Ca and Mg concentrations (Pilar et al., 2001). Del Amor et al. (2001) found that plants of a tomato cultivar exposed to nutrient solutions salinized to 4, 6 and 8 dS m^{-1} showed reduced leaf concentration of K and Ca but not Mg and increased Na concentration with increasing salinity stress compared to control at 2 dS m^{-1}. According to Cuartero and Fernandez-Muñoz (1998) Mg concentration in leaves decreases in response to salt stress as well as NO_3^-, K and Ca concentration and Na and Cl concentration increases.

Tomato plants seem to respond differently to salinity stress in regard to nutritional status of young and mature leaves. Accordingly Ca and K concentration in leaves decreases with increasing salinity concentration but mature leaves may contain almost the double amount of Ca under this stress conditions compared to young leaves and the K concentration is slightly less in younger leaves and as salinity stress intensifies mature leaves accumulate higher concentrations of Na as well compared to younger leaves, especially at low salinity stress up to 6 dS m^{-1} and at higher EC the difference is very small (Maggio et al., 2007). Maggio et al. (2007) concluded that plants are capable of adapting to salinity stress by excluding Na from the cytosol and storing it in vacuoles of the root only to a certain extend and that at higher intensity of salinity stress Na enters the transpiration flux and is transported to the shoot of the plant were it then accumulates in higher concentration in mature leaves due to longer transpiration time compared to younger leaves. Once in the transpiration stream of the plants, Na tends to accumulate in the leaf blades rather than the roots. This phenomenon explains the considerably higher Na concentration in leaves, which is in full agreement with our results (Munns, 2002).

The Na accumulated in the leaves is lowering the osmotic potential and thus actually contributing to maintain the water potential within the plant by facilitating water uptake from the saline soil solution with low osmotic potential. Thus, high Na concentration in leaves is related with salt resistance of tomato plants (Cuartero and Fernández-Muñoz, 1998). The regulation of Na concentration within the plant and especially the distribution of Na between mature and younger leaves are more likely related to salt stress resistance than accumulation of Na in leaves alone (Sacher et al., 1982; Shannon et al., 1987). The youngest three to four tomato leaves do accumulate only up to half the Na concentration in comparison to the youngest four to six leaves, while fully expanded mature leaves may saturate with Na. Once vacuoles saturates with Na, the cytosol receives the rest of the Na leading to inactivation of enzymes and finally cell death that will cause the leaves to drop once all cells are dead (González-Fernández, 1996, Cuartero-Fernández-Muñoz, 1998).

Table III. 5. Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the lower leaf tissue of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments.

		Concentration of element in ppm											
Genotype	Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
Vengador	0 mM	2450 a	3771.4 a	7628.6 a	17112 a	9823.2 a	242.78 a	1441.3 a	35.388 a	343.37 a	162.79 a	8377.5 a	936.2 a
	30 mM	2695 a	3494.3 a	4738.6 b	23332 a	12267 a	562.99 a	1705.9 a	52.287 a	335.35 a	143.83 a	17029 a	757.88 a
	60 mM	1925 b	2997 a	4701.2 b	16784 a	10062 a	226.74 a	1723.2 a	53.935 a	310.19 a	88.281 b	30699 b	1439.3 a
	90 mM	1715 b	3572 a	4990 b	14143 a	9904.8 a	192.14 a	1937 a	57.501 a	323.19 a	77.461 b	31274 b	1286.5 a
Campeche	0 mM	2205 a	2733.9 a	8682.6 a	28033 a	12923 a	199.74 b	1307.5 a	42.361 a	519.55 a	243.93 a	4099 c	1120.9 a
	30 mM	2205 a	3291.2 a	7037 a	23429 ab	13598 a	238.44 ab	1768 a	64.119 a	372.97 a	137.13 b	15897 b	993.52 a
	60 mM	1872.5 a	3607.2 a	8440.4 a	19509 b	12527 a	222.16 ab	1816.4 a	67.554 a	404.82 a	111.1 bc	33167 a	1668.6 a
	90 mM	2082.5 a	3888.4 a	6778.2 a	18092 b	9982.5 a	314.3 a	1798.3 a	62.837 a	418.05 a	97.969 c	33530 a	1649.5 a
Oaxaca	0 mM	1820 a	1985 b	10517 a	26930 a	14448 a	141.1 b	826.71 b	24.156 b	254.87 a	121.92 a	2935.2 b	802.46 a
	30 mM	2380 a	2579.9 a	11005 a	23023 ab	12921 a	233.11 a	1493 ab	60.634 a	363.06 a	116.77 a	17164 a	1082.7 a
	60 mM	2065 a	3028.9 a	12230 a	21401 ab	11616 a	230.36 a	1605.4 ab	67.385 a	369.22 a	89.046 a	21241 a	1624 a
	90 mM	1977.5 a	3021.8 a	10097 a	18185 b	10807 a	241.49 a	1547.2 a	70.185 a	381.49 a	74.041 a	24247 a	1515.8 a
Puebla	0 mM	2537.5 a	3079.5 a	11135 a	25018 a	12650 a	178.23 a	1195.7 b	42.093 b	479.63 a	215.86 a	3206.9 c	764.25 b
	30 mM	2310 a	3378.9 a	6830.3 b	26184 a	11765 a	209.75 a	1544 ab	69.438 a	438.42 a	147.76 b	9488.8 bc	1241.9 ab
	60 mM	2082.5 a	3120.1 a	5601.1 b	21435 a	11135 ab	251.41 a	1426 ab	64.913 ab	429.96 a	112 bc	19525 ab	1598.6 a
	90 mM	2170 a	3449.4 a	5525.8 b	22454 a	9850.8 b	227.17 a	1691.6 a	64.121 ab	399.4 a	86.408 c	23336 a	738.77 b
Veracruz	0 mM	1995 a	3980.6 a	10906 a	19820 a	12030 a	219.13 a	1146.2 a	71.644 a	342.7 a	306.45 a	5770 c	955.31 a
	30 mM	2082.5 a	3587.7 a	10103 a	19212 a	13165 a	257.04 a	1307.8 a	46.77 a	257.07 a	231.05 ab	14492 bc	1050.8 a
	60 mM	2170 a	3568.8 a	9041.6 a	19645 a	10077 a	264.76 a	1476 a	58.489 a	281.26 a	205.43 b	21214 ab	1649.5 a
	90 mM	1890 a	3813.9 a	8320.2 a	18416 a	11299 a	295.95 a	1532.2 a	61.589 a	338.71 a	199.69 b	29131 a	2068.6 a

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	2196.3 a	3458.7 a	5514.6 c	17843 c	10514 b	306.2 a	1701.9 a	49.8 a	328 b	118.1 cd	21845 a	1105 a
Campeche	2091.3 a	3380.2 a	7734.6 b	22266 ab	12258 a	243.7 a	1672.6 a	59.2 a	428.9 a	147.5 b	21673 a	1358.1 a
Oaxaca	2060.6 a	2653.9 b	10962 a	22385 ab	12448 a	211.5 a	1368.1 a	55.6 a	342.2 b	100.5 d	16397 b	1256.2 a
Puebla	2275 a	3257 a	7273 b	23773 a	11350 ab	216.6 a	1464.3 a	60.1 a	436.9 a	140.5 cb	13889 b	1085.9 a
Veracruz	2034.4 a	3737.7 a	9592.6 a	19273 bc	11643 ab	259.2 a	1365.5 a	59.6 a	304.9 b	235.7 a	17652 ab	1431.1 a
						NaCl concentration						
0 mM	2201.5 ab	3110.1 a	9773.7 a	23383 a	12375 ab	196.2 a	1183.5 b	43.1 b	388 a	210.2 a	4878 c	915.8 b
30 mM	2334.5 a	3266.4 a	7942.8 b	23036 ab	12743 a	300.3 a	1563.7 a	58.7 a	353.4 a	155.3 b	14814 b	1025.4 ab
60 mM	2023 b	3264.4 a	8002.8 b	19755 bc	11084 bc	239.1 a	1609.4 a	62.5 a	359.1 a	121.2 c	25169 a	1596 a
90 mM	1967 b	3549.1 a	7142.2 b	18258 c	10369 c	254.2 a	1701.3 a	63.3 a	372.2 a	107.1 c	28304 a	1451.8 ab
						P value from ANOVA						
Genotype	0.2068	<0.0001	<0.0001	0.0008	0.0123	0.4502	0.0857	0.4406	<0.0001	<0.0001	0.0001	0.644
NaCl concentration	0.0027	0.1165	0.0001	0.0004	<0.0001	0.2304	0.0028	0.002	0.5231	<0.0001	<0.0001	0.0173
Interaction	0.0599	0.1371	0.0437	0.2691	0.2885	0.3871	0.9951	0.1272	0.1511	0.0458	0.2385	0.9255

Table III. 6. Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the upper leaf tissue of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments.

		Concentration of element in ppm											
Genotype	Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
Vengador	0 mM	2870 a	3380.1 a	6514 a	16891 a	7319.8 a	159.37 a	351.46 a	26.568 a	268.24 a	124.18 a	11391 b	1461.9 a
	30 mM	2870 a	3815.2 a	7095.6 a	15030 ab	9746.5 a	177 a	259.05 a	25.093 a	290.04 a	93.8 ab	10080 b	1275.2 a
	60 mM	2397.5 a	3531.5 a	7484.8 a	12570 ab	9749.1 a	305.72 a	774.19 a	43.78 a	311.39 a	96.828 ab	27376 ab	1300.9 a
	90 mM	2905 a	3826.4 a	7947.8 a	10925 b	7907.1 a	180.64 a	735.12 a	47.016 a	267.08 a	65.64 b	31371 ab	1442.6 a
Campeche	0 mM	2660 a	3494.3 a	8358.6 a	26649 a	10927 a	225.43 a	507.16 a	46.777 b	442.22 a	179.48 a	7983.4 c	1146.4 a
	30 mM	2100 a	3495.1 a	7865.2 a	21132 ab	10737 a	265.18 a	233.09 a	33.654 ab	325.51 a	116.82 b	14099 bc	1004.1 a
	60 mM	1785 a	4304.8 a	10821 a	15993 b	8833.8 a	306.01 a	359.47 a	51.946 ab	329.91 a	110.94 b	29748 ab	1378.2 a
	90 mM	2467.5 a	4500.7 a	7912.7 a	16629 b	8560.3 a	255.24 a	847.07 a	68.814 a	447.78 a	90.325 b	37761 a	1275.2 a
Oaxaca	0 mM	3080 a	3182.5 ab	11536 a	16668 a	10322 a	146.17 a	115.27 a	22.756 b	169.11 b	70.916 a	5326.1 b	1165.7 a
	30 mM	2257.5 a	2807.7 b	11687 a	16317 a	10065 a	282.11 a	241.46 a	50.9 ab	331.18 ab	108.85 a	18257 ab	1249.4 a
	60 mM	2362.5 a	3050.8 ab	9098.7 a	17948 a	9705.3 a	190.88 a	351.12 a	50.303 ab	447.2 a	91.482 a	18282 ab	1300.9 a
	90 mM	2502.5 a	3999.9 a	12118 a	16088 a	10393 a	208.02 a	332.6 a	59.871 a	453.54 a	82.144 a	27134 b	1397.5 a
Puebla	0 mM	2782.5 a	2841.8 b	9465.5 a	17793 a	9462.4 a	214.29 a	251.07 a	48.472 a	515.86 a	135.76 a	6639.2 b	1320.3 a
	30 mM	2555 a	3050.3 ab	10273 a	15622 a	10965 a	143.85 a	275.5 a	47.452 a	391.55 a	120.05 a	12439 ab	1288.1 a
	60 mM	2415 a	3985.3 a	9649.4 a	15979 a	9911.2 a	295.79 a	300.57 a	59.956 a	387.56 a	91.912 a	27949 ab	1539.2 a
	90 mM	2765 a	4068.1 a	7621.3 a	15458 a	9769.3 a	164.09 a	400.45 a	56.822 a	388.45 a	100.89 a	26101 a	1751.8 a
Veracruz	0 mM	2695 a	3790.4 a	10562 a	16194 ab	10305 a	236.68 a	214.77 a	27.258 a	271.34 a	288.97 a	5295.3 b	1404 a
	30 mM	2362.5 a	3615.1 a	9263.2 a	16636 ab	10664 a	198.24 a	189.54 a	42.464 a	254.09 a	208.37 ab	9853.7 b	1481.3 a
	60 mM	2432.5 a	3556.4 a	10321 a	13401 ab	8718.7 a	174.04 a	202.78 a	39.369 a	288.43 a	204.55 ab	19037 ab	1326.7 a
	90 mM	2257.5 a	3432.4 a	9533 a	11628 b	8906.2 a	175.73 a	438.86 a	45.478 a	287.68 a	161.57 b	29520 a	1598.5 a

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	2760.6 a	3638.3 a	7260.6 c	13854 b	8680.6 a	205.68 a	530 a	35.6 c	284.2 b	95.1 c	20055 a	1370.2 ab
Campeche	2253.1 a	3948.7 ab	8739.4 bc	20101 a	9764.3 a	261.97 a	486.7 a	50.3 ab	386.4 a	124.4 b	22398 a	1201 b
Oaxaca	2550.6 a	3260.2 b	11110 a	16755 b	10121 a	206.79 a	260.1 a	46 abc	350.3 ab	88.4 c	17250 a	1278.4 ab
Puebla	2629.4 a	3486.4 ab	9252.2 b	16213 b	10027 a	204.5 a	306.9 a	53.2 a	420.9 a	112.2 bc	18282 a	1474.8 a
Veracruz	2436.9 a	3598.6 ab	9919.8 ab	14465 b	9648.4 a	196.2 a	261.5 a	38.6 bc	275.4 b	215.9 a	15926 a	1452.6 a
						NaCl concentration						
0 mM	2817.5 a	3337.8 b	9287.3 a	18839 a	9667.1 a	196.4 a	287.9 b	34.4 c	333.4 a	159.9 a	7327 b	1299.7 ab
30 mM	2429 ab	3356.7 b	9236.7 a	16947 ab	10435 a	213.3 a	239.7 ab	39.9 bc	318.5 a	129.6 b	12946 b	1259.6 b
60 mM	2278.5 b	3685.8 ab	9475 a	15178 bc	9383.6 a	254.5 a	397.6 ab	49.1 ab	352.9 a	119.1 cb	24478 a	1359.2 ab
90 mM	2579.5 ab	3965.5 a	9026.6 a	14146 c	9107.2 a	196.8 a	550.8 a	55.6 a	368.9 a	100.1 c	30377 a	1493.1 a
						P value from ANOVA						
Genotype	0.1523	0.0318	<0.0001	<0.0001	0.128	0.2442	0.0442	0.0009	<0.0001	<0.0001	0.2283	0.0068
NaCl concentration	0.0334	0.0034	0.8439	<0.0001	0.0842	0.1579	0.0162	<0.0001	0.2166	<0.0001	<0.0001	0.0142
Interaction	0.9454	0.1116	0.0171	0.0592	0.419	0.2627	0.7258	0.1398	0.0002	0.0033	0.6289	0.4994

Two different main groups of plants in regard to NaCl stress do exist, one group including species that accumulate high Cl concentrations rather than Na concentration in leaves and the other group accumulates higher concentrations of Na, with tomato belonging to the latter group (Munns and Tester, 2008). Hence, the focus on any investigation on salinity in tomato must be oriented to the effects of Na. Furthermore, the toxic concentration in plant tissue tolerated by most species for Cl is 400 mM, while the tolerated Na tissue concentration is only about 200 mM (Gonzáles-Fernández, 1996; Munns and Tester, 2008).

Our results show that not only is the response of tomato nutritional status to salinity stress different for genotypes but also for different parts of stem and leaves. The plants micronutritional status in relation to salinity stress is especially complex and may result in an increase, decrease or even no response to the nutriment concentration in certain genotypes (Grattan and Grieve, 1999). We found some significant effects on micronutrient concentration in some genotypes as a response to salinity stress, especially for Zn, Mn and B. Many of the investigations realized focus on only one genotype making it hard to draw conclusions to other genotypes. Moreover, we found insufficient data on tomato plant nutritional status in terms of micronutrients for different parts of a plant. Due to the results obtained in this investigation salinity affects tomato plant micronutrimental status depending on genotype and plant growth may be affected further by micronutrimental concentration changes. Although existing investigations describe a negative effect of salinity on the concentration of some essential nutriments in certain plant tissues this could not be verified for all genotypes. Cruz and Cuartero (1990) concluded that tomato plants adapt with increasing time of exposure to salinity stress and negative effects may be less severe than plants treated for less time.

There is little clear information in regard to Cl uptake and transport mechanisms in plants and the involved proteins, chloride channels may be involved in compartmentations into the vacuole and chloride cations cotransporters may be responsible for the xylem loading (Amtmann and Beilby, 2010; Munns, 2011; Mansour, 2014).

While Na concentration was similar in upper and lower part of leaves in our investigation the Cl seems to accumulate with preference in the upper part of leaves but we could not find significant differences between the treatments and control for any genotype and relate them to the experimental conditions. During the extended time of our experiment, we observed necrosis on the oldest leaves of the plants as a response to salinity stress and several leaves dropped of the plants as a result of a progressed necrosis. The accumulation of Na in these leaves, as discussed above, may proceed simultaneously with an accumulation of Cl. This might explain a missing significantly accumulation of Cl in some genotypes for some NaCl treatments.

III.4. CONCLUSIONS

The genotypes were affected negatively in growth by the salinity treatments and the nutritional status of the different plant parts showed significantly reduced concentrations for some essential elements, mainly K, Ca and Mg, while Na concentration increased. The different responses of the tomato genotypes seem to demonstrate different capabilities and strategies to deal with salinity stress. In accordance with other authors highlighting the importance of genotypes in regard to stress tolerance and plant metabolism responses to salinity we found a very individual response for genotypes of the same species. Investigations with only one genotype are only giving ideas and tendencies that might be applicable to a certain extent to other genotypes. Salinity stress not only affects macronutrient concentration, but also micronutrient concentrations, mainly Zn, Mn and B. As this response to salinity is poorly documented and investigated, it is suggested further investigation. The Cl accumulation as a response to salinity stress has been documented elsewhere, but could barely find a change in Cl concentration. The experimental design might have had an impact on these results and as investigations on Cl homeostasis and compartmentation under salinity stress is rare. It can only be can assumed that prolonged NaCl exposure does not affect significantly all parts of the plant organs of the genotypes.

III.5. LITERATURE CITED

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CAPÍTULO IV. FRUIT QUALITY PARAMETERS OF MEXICAN NATIVE LANDRACE TOMATOS AFFECTED BY SALINITY STRESS

IV.1. INTRODUCTION

The tomato (*Solanum lycopersicum* L.) fruits are a very popular and worldwide known vegetable and are appreciated for the preparation of many dishes. On a global scale the tomato is the most traded vegetable with a 22% share of the global trade (Hallam et al., 2004). The origin of the tomato is found in the Andean region from where it reached Mesoamerica and the ancient tomato was domesticated to the present form. Already when the Spaniards arrived in Mexico, tomatoes were comparable in size to modern cultivars (Blanca et al., 2015; Hernández and León, 1992). While the majority of present day Mexican national production relies on modern cultivars of the types Roma, Round and Cherry local native landrace or heirloom varieties are still produced in the states of Puebla, Oaxaca, Veracruz, Nayarit, Jalisco, Michoacán and Guerrero, among others, but these landraces usually do not leave the region of production (SIAP, 2016; Bai and Lindhout, 2007; Vargas-Canela, 2005; Bonilla-Barrientos et al., 2014; Ríos-Osorio et al., 2014).

Fruit quality is mainly defined by its nutritional value, flavor, appearance and postharvest processing. Because of high competition on a transnational tomato market, breeding efforts in the past were concentrated on yield rather than fruit quality (mainly related to flavor) (Klee, 2010). But consumer preferences are changing and more and more people demand flavorful tomatoes and tomatoes with unique characteristics and are willing to pay a considerable surplus compared to standard tomatoes (Jordan, 2007; Ekelund and Jönsson, 2011; Barndt, 2008; Brugarolas et al., 2009). Furthermore, tomatoes fulfill an important nutritional role in a balanced diet. Tomatoes not only contain sugars, fibers and proteins, but are also rich in minerals like K, P, Mg and Ca; carotenoids like lycopene, flavonoids and vitamin A, B, C, E and K (Zapata et al., 2007, Bergougnoux, 2014). Stevens (1986) found that wild relatives of the tomato may contain up to five times the vitamin C content of cultivated ones. Mexico is fighting two problems that are two extremes of the same cause. Approximately 70% of the adults have excessive weight, overweight or obesity, while 30% of the underage show this problem. At the same time in the group of the five to fourteen year old kids, 7.3% suffer from malnutrition in urban areas and 14.6% in rural areas with the indigenous population suffering the most from this malnutrition with a three times higher chance of dying from malnutrition. On the one hand tasty tomatoes may be an important part to a healthier overall nutrition as they may be consumed in higher amounts due to the superior flavor and on the other hand tomatoes with a high nutritional value may prevent some of the negative effects of malnutrition, with native landraces adapted to the rural areas and available without purchase at high prices from seed companies. The flavor of a tomato is mainly defined by sugars, acids and various volatile compounds, of which a few 100 are produced by a ripe tomato, with a wide range of concentration and combinations in each cultivar responsible for the unique flavor of some genotypes (Baldwin et al., 2000; Tikunov et al., 2005, Rambla et al., 2014).

Aoki (2003) reported an increasing consumer demand for sweeter tomatoes. To produce sweeter fruits some producers use drought and/or salt stress on tomato plants before harvest to meet this demand (Ehret and Ho, 1986; Adams and Ho, 1992). Increased tomato fruit quality was achieved by exposure to salinity stress causing increased total soluble solids content and acidity (Cuartero and Fernández-Muñoz, 1999). The acid and sugar relation are important for the tomato flavor as fruits with high acidity and low sugar concentration present a tart flavor and sweet fruits without acidity are tasteless (Grierson and Kader, 1986).

Tomato fruit texture is also affected by salinity stress but investigations showed different results. Fruit firmness may decrease due to exposure to salinity stress or no effects on fruit firmness or increased firmness were reported (Leonardi et al., 2004; Krauss et al., 2006; Flores et al., 2003). Salinity effects on lycopene concentration are still unclear, while the concentration of this compound may increase or not in response to salt stress (Krumbein et al., 2006; Dorais et al., 2000; Krauss et al., 2006). Little information about the mineral concentration of tomato fruits as affected by salinity is available and especially information regarding nutritional value of heirloom or wild genotypes is rare in scientific literature (Dorais et al., 2008). Méndez et al. (2011) showed that the fruit quality parameters of 13 Mexican landraces from different states can vary widely among characteristics like titratable acidity concentration, reduced sugars concentration, color and lycopene concentration. Therefore, our aim in this research was to determine the effect of four levels of NaCl in the nutrient solution on the quality of fruits produced by five different tomato genotypes, including four landraces.

IV.2. MATERIALS AND METHODS

The experiment was realized in the year 2015 in the Colegio de Postgraduados Campus Montecillo in Texcoco, State of Mexico (Mexico), in a greenhouse and with a drip irrigation system. Plants were obtained by germinating seeds from collections of traditional native landraces with origin in four states of Mexico: Campeche, Oaxaca, Puebla and Veracruz. The tomato types of the landraces are named according to Lobato-Ortiz et al. (2012): Kidney, Ribbed Kidney-Shaped, Chino Criollo (bell pepper shaped) and Citlale (star-tomato), respectively. Furthermore, we used one commercial hybrid of the Roma-Saladette type, Vengador (produced by Syngenta). The tomato type named as Citlale has various names throughout Mexico and might be identical to *Solanum lycopersicum* var. cerasiforme Dunal, Spooner, Anderson and Jansen (Jenkins, 1948; Rodríguez et al., 2009).

We prepared the nutrient solution according to Steiner (1984). A completely randomized experiment with 10 replications per treatment was set up. We used germination trays filled with peat moss based substrate and tap water was used for irrigation. The water pH was adjusted to 6 with 0.1 N NaOH. Twenty days old plantlets were irrigated with Steiner solution at 50% to meet nutrient demand of the plants. With 45 days of age plants were transplanted in black polyethylene bags with 10 liter capacity filled with tezontle, an inert local volcanic gravel, with mixed particle size. These plastic bags were spaced in four double rows, 160 cm between double rows and 35 cm between plants (35,714 plants ha^{-1}), and the plants then were guided with plastic rope to above installed wire at 250 cm above ground when growth made it necessary. We increased the concentration of the Steiner solution to 75% at the moment of transplant and to 100% sixty days after sowing, with a final electric conductivity of 2.4 dS m^{-1}.

For the salinity treatments we added 30, 60 and 90 mM of NaCl to the solution to increase the electric conductivity to 5.4, 8.4 and 11.4 dS m^{-1}, respectively, for the plants 70 days after sowing. Agrochemicals were applied when necessary, according to technical recommendations, to achieve healthy plant growth. Suckers and lower leaves were pruned when necessary for adequate growth performance. Harvest was realized when maturity of fruits made it necessary. All fruits ripped to full maturity on the plant and fruits were directly frozen at -80 °C after picking to analyze EC value, lycopene concentration, reduced sugars concentration and titratable acidity. EC value was analyzed with a EC meter (J.T. Baker Conductronic PC18; Phillipsburg, New Jersey, USA), We duplicated each lecture for reduced sugars concentration according to the method of Somogyi-Nelson (Somogyi, 1952). Titratable acidity concentration was analyzed with titration with 0.1 N NaOH according to the AOAC (1990).

Some fruits were cut into pieces and dried at 65 °C until constant weight in a forced air drying oven (Riossa HCF-125D; Guadalajara, Jalisco, Mexico) to obtain the nutrimental composition by wet digestion with sulfuric acid and analysis in. We used some fruits directly after picking for the analysis of firmness with a texture meter FDV-30 (Greenwich, CT 06836, USA) using a 0.8 mm cone at the equatorial region of the fruit and on the opposite site and analysis of color with a color meter Hunter Lab D25-PC2 (Reston, Virginia, USA) at the equatorial region of the fruit and on the opposite site to obtain the L, A and B value of the CIELAB color space. All analyzes were realized with 5 repetitions, except nutrimental concentration which was realized with 4 repetitions. All data was subject to analysis of variance (ANOVA) using the GLM procedure of SAS ver. 9.3 (SAS, 2011) to detect tomato response to NaCl and mean separation was realized with Tukey's range test. Predetermined significance level was set up with alpha equal to 0.05.

IV.3. RESULTS AND DISCUSSION

All genotypes showed significant responses in EC value of fruits to the salinity treatments. The EC value gives an indirect information about the concentration of diluted salts in the fruit juice. The EC value increased for all genotypes with increasing salinity stress but differences between the genotypes were evident. The Campeche landrace showed the highest EC values for all treatments and Puebla the lowest for control and the 30 mM treatment. Oaxaca had the lowest EC value at the 60 mM treatment and Vengador at the 90 mM treatment. Puebla showed just 56% of the EC value of Campeche under control conditions while Vengador reached 79% of the EC of Campeche under the 90 mM treatment (Figure IV. 1). We could not find reports of EC value of tomato fruit juice as affected by salinity stress.

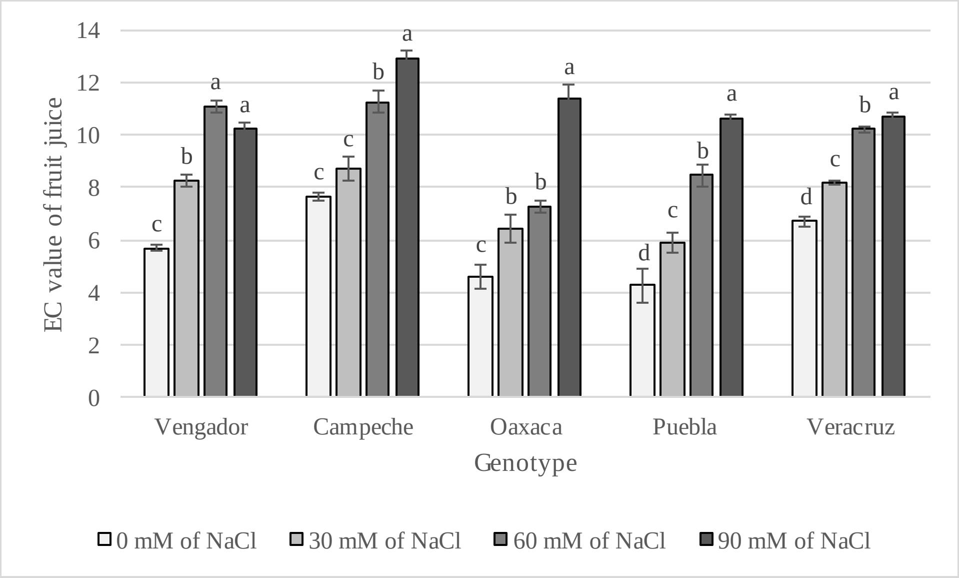

Figure IV. 1. Average EC value of tomato fruits of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

The lycopene concentration was influenced by the salinity stress treatment in the case of Campeche and Vengador. For Campeche the lycopene concentration was 53% elevated at the 60 mM treatment compared to control and although the 90 mM treatment showed a 33% increase the difference was not significant. In the case of Vengador we found a 40% increase of lycopene concentration at the 60 mM treatment compared to control and although the 30 and 90 mM treatment showed elevated concentration the difference was not significant (Figure IV. 2).

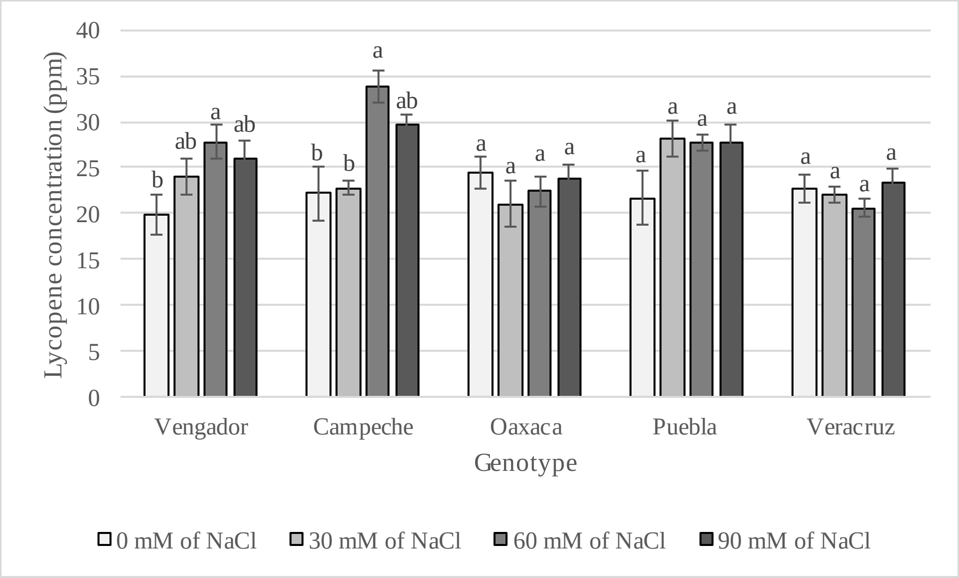

Figure IV. 2. Average lycopene concentration of tomato fruits of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Giannakoula and Ilias (2013) found an increase of lycopene concentration in tomato fruits at 150 mM of NaCl but not at 100 mM compared to a control without NaCl addition, while Borghesi et al. (2011) could find a significantly increased lycopene concentration in four tomato cultivars with a nutrient solution at 5.5 dS m^{-1} compared to control at 2.5 dS m^{-1}. The lycopene concentration may increase at low intensities of salinity stress because of an up regulation of the gene encoding for enzymes responsible for key steps in the lycopene biosynthesis but high salinity stress intensity may also decrease lycopene concentration and high variation exists between genotypes (Dorais et al., 2008). Effects of salinity on lycopene concentration may be related to other conditions of growing at the same time as Ehret et al. (2013) showed no significant differences in lycopene concentration in one year but did so in another year with the same experimental setup.

Campeche and Oaxaca showed a significantly increased reduced sugars concentration at the 90 mM treatment compared to the other treatments while the Veracruz landrace increased the reduced sugars concentration significantly at the salinity stress treatments compared to control. Campeche showed increased reduced sugars concentration at the 30 and 60 mM treatments as well, but difference was not significant. The difference in sugars concentration between the control and the 90 mM treatment for Campeche was a 460% higher, while the increase for Oaxaca was only 82%. The increase between control and the 90 mM treatment for Veracruz was 44% (Figure IV. 3).

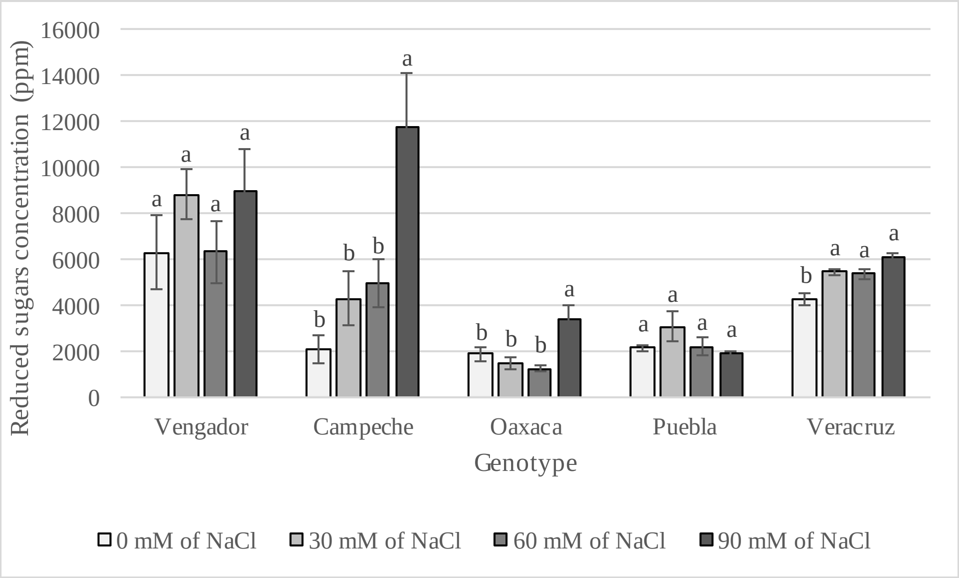

Figure IV. 3. Average reduced sugars concentration of tomato fruits of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Other investigations found an increased reduced sugars concentration due to salinity stress as well. (Sgherri et al., 2008; Del Amor et al., 2001).

Titratable acidity concentration in fruits was affected by treatments for all genotypes but Campeche. The tendency is an increase of titratable acidity concentrations for the genotypes with increasing salinity stress. Oaxaca showed the lowest concentration for control conditions as well as for the 30 mM and 60 mM treatment and Vengador showed a drastic decline at the 90 mM treatment resulting in the lowest concentration for this treatment. Campeche developed the highest concentration in fruits under control conditions, 85% higher than the Oaxaca concentration, while Veracruz had the highest concentration with treatments of salinity stress, with the 90 mM treatment concentration being 74% higher than the concentration of Vengador (Figure IV. 4).

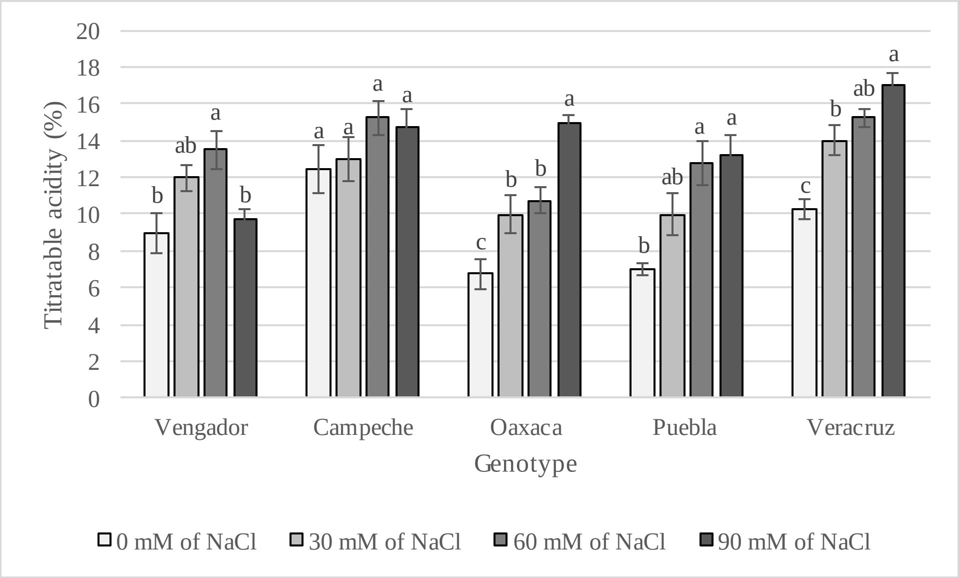

Figure IV. 4. Average titratable acidity concentration of tomato fruits of five genotypes of tomato in response to four levels of NaCl added to the nutrient solution. The values represent the mean of ten repetitions ± standard deviation. Distinct letter in each genotype, indicate significant differences among treatments.

Sgherri et al. (2008), Del Amor et al. (2001) and Sato et al. (2006) have reported that an increase in titratable acidity may be due to increase saline stress. The increased concentration of acids and sugars in tomato fruits exposed to NaCl stress is explained with a reduced fruit water content and thus concentrated more acids compared to non-stressed fruits (Leonardi et al., 2004). Furthermore Saito et al. (2008) showed that the tomato pericarp cells size is reduced in response to salinity stress, which could concentrate sugars and acids even more.

The nutrient concentration of fruits varied widely with treatments and genotypes but K, Cu and Na concentration was affected for all. Cu concentration variation might be due to application of agrochemicals. In the case of Campeche there was attendance of increasing N concentration due to salinity stress but difference was only evident for the 30 mM treatment compared to control. The response of P concentration was differentiated. While for Campeche an increase at 30 mM NaCl was registered, the concentration declined at 60 and 90 mM compared to control. For Puebla the P concentration declined due to salinity stress and for Vengador a decline was only significant at the 30 mM treatment compared to the others. In the case of the K concentration we found a clear tendency of decrease as a consequence of salinity stress exposure, except for Vengador, but differences between the genotypes in magnitude were evident. While Oaxaca had the highest K concentrations at control, the 30 and 90 mM treatment conditions Vengador had the highest at 60 mM. Veracruz showed the lowest concentrations at 60 and 90 mM of NaCl. For Vengador and Puebla we found a clear decrease of Ca concentration for the treatments with NaCl compared to control. The Campeche and Oaxaca landraces showed mixed responses that seem hard to be related to our experimental conditions. For the Mg concentration we found for all genotypes, except for the Veracruz landrace, a tendency of decrease with increasing salinity stress, though differences were only significant in some cases. The salinity stress seems to increase the Fe concentration in fruits of Vengador and Oaxaca but results were inconsistent. The treatments with NaCl reduced Zn concentration in Puebla significantly as they reduced Mn concentration for Puebla and Vengador. The B concentration was reduced for Oaxaca and Puebla as a result of salinity stress. The biggest effect on mineral concentration due to salinity stress was observed for Na concentration. An increase of Na concentration was evident in direct relation to NaCl concentration, although genotypes responded in different intensity. Campeche showed the highest Na concentration in the control, 60 and 90 mM treatment while Veracruz showed the lowest concentration at the 60 and 90 mM treatments. Campeche showed an increase of 393% for the Na concentration from control to the 90 mM treatment, while Veracruz only showed a 166% increase. We could not find significant differences for the Cl concentration except for Oaxaca, albeit results in observed in Oaxaca fruits are unclear (Table IV. 1).

Table IV. 1. Effect of four treatments of NaCl applied in the nutrient solution on the concentration of the elements N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B, Na and Cl in ppm in the fruits of five genotypes of tomato. Values are means of four replicates. Distinct letter after means indicate significant differences among treatments

		Concentration of element in ppm											
Genotype	Concentration of NaCl	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
Vengador	0 mM	16625 a	3975 a	9361.5 c	1669.7 a	1487.1 a	49.518 bc	8.143 b	24.522 a	23.547 a	15.887 a	907.19 d	390.19 a
	30 mM	15925 a	3450 b	11312 ab	1200.1 b	1426.7 ab	78.652 a	13.157 a	25.406 a	16.881 b	15.874 a	3335 c	1095.3 a
	60 mM	20475 a	4181.6 a	11747 a	1118.4 b	1432.8 ab	59.036 b	9.3885 b	22.139 a	16.011 b	16.542 a	4618.6 a	465.48 a
	90 mM	16625 a	4011.7 a	10563 b	1132.1 b	1304.3 b	43.922 c	9.5438 b	23.078 a	15.229 b	18.269 a	3779.4 b	492.87 a
Campeche	0 mM	25200 b	4775 b	11990 a	1257.9 bc	1521 b	52.089 a	11.804 c	24.395 ab	21.334 a	18.198 a	1151.7 d	299.01 a
	30 mM	28350 a	5173.1 a	12414 a	1469.9 a	1788.7 a	122.59 a	15.84 a	29.358 a	22.71 a	16.915 a	2975.9 c	433.54 a
	60 mM	27300 ab	4449.4 c	9940.9 b	1113.3 c	1437.6 b	98.777 a	14.453 b	21.442 b	17.308 b	19.023 a	5819.1 a	387.51 a
	90 mM	25725 ab	4404.2 c	10200 b	1340.1 ab	1481.2 b	76.985 a	15.801 a	24.586 ab	22.51 a	17.002 a	5055.4 b	479.18 a
Oaxaca	0 mM	24150 a	4589.8 a	12902 a	1861.7 b	1968 a	58.411 b	18.181 a	32.774 a	22.774 b	19.701 a	931.87 c	597.83 a
	30 mM	28175 a	4387.7 a	12966 a	2131.9 a	2154.6 a	78.093 a	17.618 ab	32.865 a	28.621 a	19.601 a	3851.7 b	305.76 b
	60 mM	23625 a	4132.3 a	10737 b	1434.9 c	1602.5 b	74.497 ab	15.183 b	30.106 a	26.17 ab	16.499 b	4779.1 a	360.52 ab
	90 mM	30450 a	4396.6 a	11258 ab	1387.7 c	1627.3 b	67.499 ab	17.31 ab	31.427 a	24.199 b	15.857 b	4047.7 b	301.79 b
Puebla	0 mM	26425 a	4449.1 a	10489 a	1669.9 a	1547.5 a	114.75 a	13.255 a	34.19 a	26.239 a	18.634 a	877.67 c	342.27 a
	30 mM	7350 a	3526.1 c	10348 a	1235.9 b	1367.2 b	170.11 a	10.937 b	27.801 b	18.506 b	16.254 b	2689.3 b	415.29 a
	60 mM	22517 a	3972.7 b	9735.7 b	1126 b	1286.7 bc	49.679 a	11.077 b	26.045 b	14.968 c	18.537 ab	3426.5 a	561.32 a
	90 mM	21350 a	4047.1 b	9664.3 b	1218.9 b	1234 c	48.285 a	11.538 b	26.625 b	14.75 c	16.987 ab	3289.5 a	475.6 a
Veracruz	0 mM	21525 a	4235 a	9971.4 a	2006.8 a	1724.9 a	149.55 a	13.684 b	29.468 a	23.402 a	21.181 a	981.52 b	497.43 a
	30 mM	20475 a	4631.3 a	9880.3 b	2059.4 a	1751.4 a	55.296 a	22.332 a	28.568 a	18.455 a	22.475 a	2796.3 a	415.29 a
	60 mM	19775 a	4369.9 a	8385.5 ab	1688.6 a	1489.7 a	53.472 a	16.319 b	26.593 a	18.989 a	22.39 a	2805.2 a	488.3 a
	90 mM	22750 a	4214.2 a	8486.8 ab	1676.9 a	1514 a	66.536 a	16.721 b	27.716 a	18.229 a	20.05 a	2605.5 a	533.94 a

	Concentration of element in ppm											
Treatment	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B	Na	Cl
						Genotype						
Vengador	17413 c	3904.6 c	10746 b	1280.1 c	1412.7 c	57.8 a	10.1 d	23.8 c	17.9 d	16.6 b	3160 c	610.9 a
Campeche	26644 a	4700.4 a	11136 b	1295.3 c	1557.1 b	87.6 a	14.5 b	25 c	21 b	17.8 b	3750 a	399.8 a
Oaxaca	26600 a	4376.6 b	11966 a	1704.1 b	1838.1 a	69.6 a	17.1 a	31.8 a	25.4 a	17.9 b	3402.6 b	384.6 a
Puebla	23835 b	3998.8 c	10059 c	1312.7 c	1358.8 c	95.7 a	11.7 c	28.7 b	18.6 cd	17.6 b	2570.7 d	448.6 a
Veracruz	21131 b	4362.6 b	9181 d	1857.9 a	1620 b	81.2 a	17.3 a	28.1 b	19.8 cb	21.5 a	2297.1 e	479.2 a
						NaCl concentration						
0 mM	22785 a	4404.8 a	10943 a	1693.2 a	1649.7 a	84.86 a	13 b	29.1 a	23.5 a	18.7 a	970 d	423.1 a
30 mM	23595 a	4233.6 ab	11384 a	1619.4 a	1697.7 a	100.95 a	16 a	28.8 a	21 b	18.2 a	3129.7 c	568.2 a
60 mM	22738 a	4221.2 b	10109 b	1296.2 b	1449.9 b	67.1 a	13.3 b	25.3 b	18.7 c	18.6 a	4289.7 a	453.4 a
90 mM	23380 a	4214.8 b	10035 b	1351.1 b	1432.2 b	60.65 a	14.2 b	26.7 b	19 c	17.6 a	3755.5 b	444.4 a
Genotype	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.632	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.2495
NaCl concentration	0.693	0.0201	<0.0001	<0.0001	<0.0001	0.3192	<0.0001	<0.0001	<0.0001	0.0643	<0.0001	0.5126
Interaction	0.002	<0.0001	<0.0001	<0.0001	<0.0001	0.534	<0.0001	0.0053	<0.0001	<0.0001	<0.0001	0.2133

Most investigations regarding tomato nutritional value concentrate on macronutriments, vitamins and secondary metabolites. Little information on its mineral content is available, especially as effected by salinity stress. A decline in tomato fruit concentration of nitrate, P, K and Mg was reported when the EC value of the nutrient solution was increased from 0.5 dS m^{-1} to 15.7 dS m^{-1} (De Pascale et al., 2001). A decreasing K concentration in tomato fruits with increasing NaCl stress was demonstrated by Babu et al. (2012). Conversely, using 5 and 8 dS m^{-1} in the nutrient solution K concentration was increased in fruits (Sakamoto et al., 2015). Del Amor et al. (2001) showed a decrease of nitrate, Ca, K and Mg concentrations and an increase of Cl and Na concentration due to salinity stress in tomato fruits.

The effect of the salinity treatments on the color of fruits was limited. We found an increase of the lightness (L) value for Vengador due to salinity stress treatments and for Puebla for the 30 and 60 mM treatments compared to control. Treatments had no effect on the red color (A) value. The yellow color (B) value was decreased for Vengador at the 30 mM NaCl treatment compared to the 90 mM treatment, albeit our results do not show a clear tendency (Table IV. 2).

Table IV. 2. Effect of four treatments of NaCl applied in the nutrient solution on the CIELAB color values L, A and B and the firmness of fruits of five genotypes of tomato. Values are means of five replicates. Distinct letter after means in each column and source of variation indicate significant differences among treatments.

		CIELAB color values			
Genotype	Concentration of NaCl	A	B	L	Firmness in N
Vengador	0 mM	22.5 a	15.04 ab	30.98 b	25.52 a
	30 mM	19.98 a	13.98 b	34.88 a	27.6 a
	60 mM	20.64 a	15.14 ab	36.78 a	25.24 a
	90 mM	21.88 a	16.06 a	37.54 a	28.32 a
Campeche	0 mM	18.5 a	8.32 a	30.26 a	13.32 a
	30 mM	21.4 a	8.96 a	31.88 a	14.12 a
	60 mM	22.5 a	9.34 a	31.76 a	14.8 a
	90 mM	19.32 a	8.24 a	31 a	9.88 a
Oaxaca	0 mM	18.82 a	9.88 a	31.54 a	19.4 a
	30 mM	16.78 a	9.42 a	30.66 a	14.48 a
	60 mM	18.32 a	9.52 a	32.46 a	17.8 a
	90 mM	20.42 a	9.84 a	34.16 a	17.96 a
Puebla	0 mM	22.42 a	10.04 a	27.02 b	25.6 b
	30 mM	22.94 a	11.16 a	33.38 a	33.36 ab
	60 mM	21.28 a	10.12 a	34.98 a	35.24 ab
	90 mM	21.52 a	9.8 a	33.1 ab	43.44 a
Veracruz	0 mM	20.48 a	12.2 a	29.32 a	7.64 a
	30 mM	24.14 a	14.92 a	28.12 a	8.04 a
	60 mM	23.24 a	14.1 a	27.86 a	10.88 a
	90 mM	21.82 a	13.74 a	28.1 a	8.4 a

	CIELAB color values			
Treatment	A	B	L	Firmness in N
		Genotype		
Vengador	21.3 ab	15.1 a	35.1 a	26.7 b
Campeche	20.4 ab	8.7 d	31.2 b	13 d
Oaxaca	18.6 b	9.7 cd	32.2 b	17.4 c
Puebla	22 a	10.3 cd	32.1 b	34.4 a
Veracruz	22.4 a	13.7 b	28.4 c	8.7 e
		NaCl concentration		
0 mM	20.5 a	11.1 a	29.8 b	18.3 b
30 mM	21.1 a	11.7 a	31.8 a	19.5 ab
60 mM	21.2 a	11.6 a	32.8 a	20.8 ab
90 mM	21 a	11.5 a	32.8 a	21.6 a
		P value from ANOVA		
Genotype	0.0011	<0.0001	<0.0001	<0.0001
NaCl concentration	0.8852	0.4001	<0.0001	0.0494
Interaction	0.2166	0.1115	0.0007	0.0002

Del Amor et al. (2001) found a tendency of increased A values for tomatoes exposed to salinity stress but no changes for B and L value. Plants exposed to a nutrient solution of 8 dS m^{-1} at the state of flowering produced fruits with increased L, A and B values compared to control plants (Saito et al., 2008). Borghesi et al. (2011) found that salinity stress significantly increased the L value in a tomato cultivar, while three others were not affected. Indeed, the A value was significantly reduced in one cultivar, while the B value was elevated for two cultivars. These results were attributed to different concentrations of carotenoids and/or anthocyanins in the tomato fruits, depending on genotype.

The firmness was only influenced by salinity for the Puebla landrace. A significant increase of firmness at the 90 mM treatment compared to control was found, resulting in 70% more firmness (Table VI. 2).

Firmness of tomato fruits was reported to increase as a response to salinity stress (Del Amor et al., 2001; Sato et al., 2006, Saito et al., 2008) An investigation with five cherry tomato cultivars showed that plants after approximately eight to nine month of treatment with salinity stress developed higher firmness and increased thickness of tomato fruit skin that was correlated positively with increased salinity (Ruiz et al., 2015). Cuartero et al. (1996) reported that firmness of fruits remains unchanged at salinity treatments of 50 mM NaCl.

IV.4. CONCLUSIONS

The effects of salinity on the five tomato genotypes tested showed a wide range of responses. Salinity stress seems to improve nutritional value of some genotypes as some mineral and lycopene concentrations were elevated in some genotypes. The increased EC value may indicate a higher content of nutritional components in the fruits due to salinity stress. The perceived taste improved by exposure to salinity stress as sugar content and acidity increased. Fruit firmness and color were almost not affected by our investigation. Salinity stress can be used to improve some fruit quality parameters, but genotypes respond are markedly different and an implicated yield decline due to salinity stress must be considered by producers.

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CAPÍTULO V. COMPARTIVE MARKET ANALYSIS OF LANDRACES AND SALADETE TOMATOES IN THE REGION OF THE HIGH MOUNTAINS IN VERACRUZ, MEXICO

V.1. INTRODUCTION

Tomato has its origins in the Andean region but Mexico is considered the place of origin of the domesticated modern tomato (*Solanum lycopersicum* L.) and the word tomato itself has its roots in the Nahuatl language, spoken by some of the Mexican indigenous people (Blanca et al., 2015, Weimann and Heinrich, 1996). On arrival of the Spanish conquerors, tomatoes, comparable in size to modern cultivars, were already reported (Hernández and León, 1992). Nowadays a wide range of cultivars of different types, sizes, shapes, colors and flavors exist and many cultivars are bred for a certain purpose, most importantly yield, but also resistances and tolerances to certain stress factors. The typical red tomato of round shape is the most famous one and is well known all around the world. Each national market prefers other types of tomatoes. In Mexico Roma (Saladette) tomatoes are favorited followed by round tomatoes (SIAP, 2016).

Tomato is the world’s most important traded vegetable with a 22% share of the total global vegetable trade (Hallam et al., 2004). In Mexico, tomato is an important agricultural product, not only culturally but also economically. For the year 2013 Mexico is listed as the number 10 of the world’s largest tomato producers in regard to net production value as well as production quantity (FAOSTAT, 2016). But with 1055 million USD value of tomato exportation in 2014 Mexico is the world’s largest tomato exporting country (SAGARPA, 2015). The production of tomato is concentrated in the north-eastern states of Mexico, with Sinaloa leading the production with a 35% share of the national production volume, followed by Baja California with 9%. A share of 95% of the tomatoes are exported to the NAFTA partners with the USA covering 80% of their tomato import with imported Mexican fresh tomatoes (SAGARPA, 2010; 2016).

In the years before 1948 Sinaloa and parts of Tamaulipas were important areas for the export market production, mainly to supply the USA in the winter season with US varieties. Production of Mexican varieties for the national market was concentrated to Veracruz, Puebla and Jalisco. An important Mexican tomato genotype is the wild ancestor of the modern tomato, the *Solanum lycopersicum* var. cerasiforme Dunal. This variety is a small fruited, round, mostly red fruit with high seed content and is dispersed in almost all parts of Mexico were growing conditions are not to harsh. Due to its high distribution, various names exist in different regions including Citlale, jaltomate, miltomate, tomatillo, chiltomate, tomate de cereza, tomate silvestre, chinana, mehen p´ak, tsajal chichol and chusma. This variety grows wild, is cultivated in backyards and agricultural used area or sown and/or cultivated on purpose. Fruits are sold in various local markets and are valued for their supreme flavor (Jenkins, 1948; Rodríguez et al., 2009; Lobato-Ortiz et al., 2012; Ríos-Osorio et al., 2014).

Little information is documented for the production practices of Mexican landraces. Production of landraces in Oaxaca relies heavily on traditional agricultural practices. Soil management is realized mostly with yoke, plastic mulch and row cover are little in use and most plants are not guided vertically. But chemical fertilizers and pesticides are commonly applied (Estrada-Castellanos et al., 2011).

The production of native landraces, called “criollo” in Mexico, is still important in many regions of the country but scientific information on production volume and market structure is scarce. The states of Puebla and Oaxaca still cultivate a large variety of native landrace varieties, including Ojo de Venado, Cherry (Citlale), Chino Criollo and kidney shaped tomatoes (Bonilla-Barrientos et al., 2014). For the regions Tehuantepec and Juchitán in the state of Oaxaca, a production of various types of landraces was investigated with ribbed-kidney shaped large fruits, with more than 400g of weight per fruit, and Citlale being the most appreciated in local markets (Ríos-Osorio et al., 2014). Moreno-Ramirez (2010) considers the regional markets of the state of Oaxaca as an important center of traditional varieties and states that many consumers prefer these varieties, for their superior flavor, even at high elevated prices compared to commercial varieties.

Barndt (2008) recognized that Canadian consumer preferences of fresh market tomatoes may change quite rapidly, within six years, with increasing interest in local small-scale production and higher product variety and Ekelund and Jönsson (2011) report a similar tendency for the European tomato market. A study with Spanish landraces showed that consumers are willing to pay a surplus of 58% to 84% for a perceived higher quality of the product and local production and that producers can compensate higher production costs, which are implicated by low yielding performance and higher risk of yield reduction by pests (Brugarolas et al., 2009). Tomato producers in Northern Europe are facing strong competition from low cost producers in southern countries of Europe and use product differentiation to present unique products instead of commodities to consumers (Ekelund and Jönsson, 2011).

Heirloom tomatoes become increasingly popular among US consumers that are looking for a flavorful variety of the product tomato (Jordan, 2007). Depending on the definition, landrace tomatoes may be heirloom as well. Niche markets can be an important opportunity for small-scale farmers that know to advertise the special value of their products; which can include unique production practices, location of production and variety of the product, as in the case of tomato, landraces or heirloom tomatoes (Von Bailey and Ward, 2007). The aim of this study was provide information about the potential market of landrace tomatoes in Mexico and countries with current or future demand.

V.2. MATERIALS AND METHODS

The study was carried out in the central region of the Mexican state of Veracruz, including the municipalities of Coscomatepec de Bravo, Orizaba, Huatusco de Chicuellar, Chocamán, Tequila, Rafael Delgado, Ixtaczoquitlán, Córdoba, Zongolica, Nogales, Ciudad Mendoza, Rio Blanco, Omealca, Cuitláhuac, Acultzingo, La Perla and Fortín de las Flores. Data was collected in April and May of 2016. This time of the year has abundance of local landraces as yield decreases heavily with the following rainy season. The climate of the region varies widely depending on altitude with many microclimate regions. Figure V. 1 shows the investigated municipalities in color in which abundance of landraces for selling purposes was found.

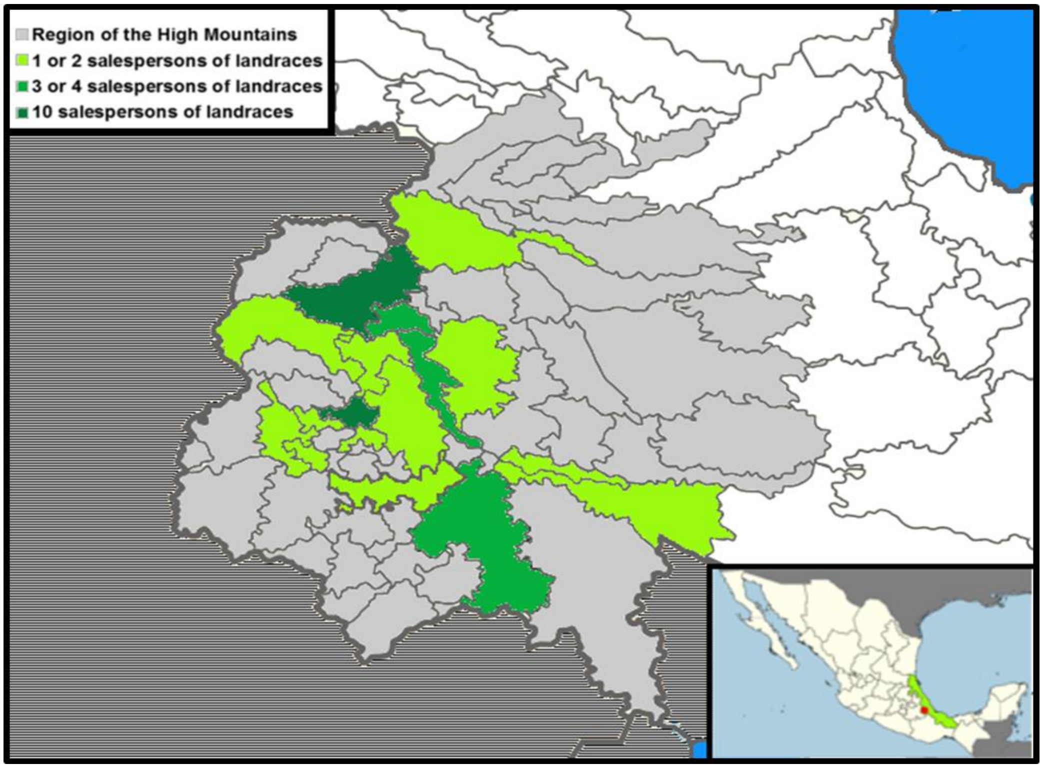

Figure V. 1. Map of the High Mountains Region (grey) in the state of Veracruz, Mexico, with area of survey colored in green tones depending on salespersons abundance. Source: Own elaboration with open content material and data from investigation.

The information was obtained by 101 surveys including questions in the topics: general information of the interviewee, information of producers and production, information of traders, channels of commercialization and product price. Persons interviewed were randomly selected from the total population of tomato selling persons at a certain local market of a municipality of the study region. In case of data collected for tomatoes of the Saladette type, the number of salespersons represents 10% of the total number of salespersons that offered Saladette tomatoes. In case of the landrace tomatoes, the number represents the total number of salespersons. The statistical analysis is descriptive with the answers to a question being expressed as a percentage of the total answers given or an average of the collected data.

V.3. RESULTS Y DISCUSSION

The basic characteristics of the interviewed persons can be summarized as 45% male and 55% female, with 45.2 years of age, 8% under 20 years of age, 31% between 21-40, 45% between 41-60, 17% older than 60 years. From all person interviewed only 27% were producing and selling their product, the others were traders who were buying the tomatoes (landraces and commercial genotypes) for selling. The most popular tomato produced is Citlale with a share of 48% of the mentioned tomato varieties in production. This tomato is popular in many Mexican states were it receives different names. In many cases it might by identical to the botanical variety *Solanum lycopersicum* var. cerasiforme Dunal. Due to its high distribution in Mexico and its special relationship with traditional agricultural systems, it may be considered as a landrace. This botanical variety is adapted to many climates, soils and altitudes. The landrace Ojo de Venado is the second most popular with 32% of the producers cultivating it. The fruits are much larger than Citlale. Also fruits are mostly not perfectly globe shaped as those of Citlale and have a thicker skin. Some varieties of this landrace may show ribbed fruits and fruits with flattened shape (Ladewig et al., 2016a). Only 12% of the producers in the region cultivate Saladette type tomatoes and 8% are producing tomatoes of the Chino Criollo landrace. This landrace is reported to be popular in the state of Puebla and fruits of this landrace may be larger and of better quality than Saladette type tomatos (Bonilla-Barrientos et al., 2014). The availability of this landrace in some markets of Veracruz may give evidence to an increasing acceptance of this landrace even in other states.

The preference for a certain fruit type seems to vary by region. In the region Tehuantepec-Juchitán, in the Mexican state of Oaxaca, most producers (22.3%) prefer large fruits of the ribbed-kidney shaped type, the Ojo de Venado is preferred by 15.6% and the Citlale by only 11.1%, among other landraces (Ríos-Osorio et al., 2014).

It was not possible to obtain data on yields for the landraces cultivated in the area. Ladewig et al. (2016b) reported that some Mexican landraces have a high yield potential compared to a common Saladette type cultivar with a kidney shaped landrace yielding 98% of the cultivar and a ribbed shaped type yielding 91% of the cultivar.

The production in the investigated region is rather traditional. Only 52% of the producers are using external inputs for production. Fertilizers, mineral and/or organic, are the most popular inputs used by 77%. Irrigation is used by 62% and agro chemical products by 54%. The cultivation technique of guiding of plants with wire and/or rope is only used by 38% of the producers. The landraces Citlale and Ojo de Venado are generally not guided. Plants are of a determinate growth and are cultivated as bushy forms without removal of suckers.

Table V. 1. Production capacity and type of production input of the interviewed producers of tomatoes for the investigated municipalities.

Municipality	Total agricutural used area (m²)	Area used for tomato culture (m²)	Tomato type cultivated	Input				
				Fertilizer	Pesticides	Buying seeds/plants	Irrigation	Wire/rope for plant guiding
Actlacjo	500	250	Ojo de Venado	yes	no	no	no	no
Acultzingo	50000	6500	Citlale/ Saladette	no	no	no	no	no
Cacahuatal	850	10	Citlale	no	no	no	no	no
Calcahualco	70000	500	Ojo de Venando	yes	yes	no	no	no
Coscomatepec	55000	5086	Ojo de Venando/ Saladette	yes	yes	yes	no	yes
Cuhautlamanca	4500	20	Citlale	no	no	no	no	no
Dos Caminos	1025	50	Ojo de Venado	yes	no	no	no	no
Huatusco	20000	7	Citlale	no	no	no	no	no
Mojuapan	4000	1500	Saladette	yes	yes	yes	yes	yes
Naranajal	10000	50	Ojo de Venado	no	no	no	no	no
Orizaba	300	10	Citlale	no	no	no	no	no
Rafael Delgado	5000	100	Citlale	no	no	no	no	no
San Francisco	25000	10000	Chino Criollo	yes	yes	yes	yes	yes
San Juan del Río	300	30	Citlale	no	no	no	no	no
Tehuacan	20000	10020	Chino Criollo/ Citlale	yes	yes	no	yes	yes
Tlapextlipa	23000	10	Citlale	yes	no	no	yes	no
Tomatlan	200	10	Citlale	no	no	no	no	no
Tonalisco	50000	10000	Ojo de Venado	no	no	no	no	no
Zapoapan	200	20	Ojo de Venando	no	no	no	no	no
Zomajapa	20000	10000	Citlale	no	no	no	yes	no

The most important month for tomato production is May, with 67% of the producers reporting yields, followed by April (59%) and March (33%). The least production was investigated for July with only 15% of the producers reporting yields. For all other month 19 to 22% report yields. Interestingly the Chino Criollo tomatoes are produced year round in Tehuacán in greenhouses and some also on fields. Only one producer reported to produce Ojo de Venado all year. Most producers limit the cultivation on certain month and due to limited use of modern cultivation techniques, mainly greenhouses and foil tunnels, yield and production decline heavily with the beginning of the rainy season in June. Plants will suffer from diseases making production for most impossible. Due to colder climate in the winter month, most producers begin in January and February with seeding so yield increases in March. All producers manage tomato production as a part time culture and are earning their livelihood with other agricultural products. Therefore the area dedicated to tomato culture is relatively small compared to the total area used by the farmers to cultivate other agricultural products. Only 537 m^2 are used for tomato production per producer in average. This observation matches with those of Ríos-Osorio et al. (2014) reporting that the area used for the cultivation of tomato landraces is commonly less than 2400 m^2 and that the harvest season is limited to two month for most farmers, with a few managing to harvest 3 or 4 months, due to climatic limitations.

A total of 41% of the producers is buying tomatoes additionally for reselling. The most popular tomato, which is bought for selling, is Saladette, bought by 75% of the salespersons, followed by Citlale (15%), Ojo de Venado (11%) and Chino Criollo (4%). The weekly quantity of tomatoes Saladette bought by all the salespersons is 56.5 t which is 855.5 kg per salesperson as a mean. By quantity, the Chino Criollo is the second most important tomato type bought for sale with 2370 kg weekly (790 kg/salesperson) followed by Citlale with 190 kg (14.6 kg/salesperson) and Ojo de Venando with 150 kg (16.7 kg/salesperson) per week. So in terms of consumption the Saladette tomato is by far the most popular one sold in the region of investigation. The average price paid by the salespersons per kg of Saladette tomatoes, for different grades of quality, at the Central de abasto/markets/producers was 6.5 MXN. The average price for Citlale was 11.2 MXN/kg, for Ojo de Venado 10.6 MXN/kg and for Chino Criollo 5 MXN/kg.

Table V. 2. Quantity bought weekly and price of buying for salespersons for each tomato type in the surveyed area for each city in which tomatoes are bought.

City	Citlale		Ojo de Venando		Chino Criollo		Saladette	
	Quantity bought (kg)	Price kg^{-1} (MXN)	Quantity bought (kg)	Price kg^{-1} (MXN)	Quantity bought (kg)	Price kg^{-1} (MXN)	Quantity bought (kg)	Price kg^{-1} (MXN)
Campo Grande	10	12	0	0	0	0	0	0
Chocamán	0	0	30	8	0	0	450	10
Ciudad Mendoza	0	0	0	0	0	0	900	7
Córdoba	0	0	0	0	0	0	1830	6.6
Coscomatepec	58	13.3	100	10.7	0	0	150	8
Fortín de las Flores	10	15	10	10	0	0	0	0
Huixcolotla	0	0	0	0	0	0	10700	6.5
Morelos	0	0	0	0	0	0	210	4
Nogales	0	0	0	0	0	0	30	7
Orizaba	10	8	10	14	0	0	7620	6.8
Portrerillo	10	10	0	0	0	0	0	0
Puebla	0	0	0	0	2250	6	33570	5.8
Rafael Delgado	22	10.7	0	0	0	0	0	0
San Francisco	0	0	0	0	120	3	0	0
San Juan	60	12.5	0	0	0	0	0	0
Santana	10	5	0	0	0	0	0	0
Zacatecas	0	0	0	0	0	0	750	6

The average price for selling was 8.3 MXN/kg for Saladette, 31.4-47.5 MXN/kg (9.5 per bowl) for Citlale, 28.4-43 MXN/kg (8.6 per bowl) for Ojo de Venando and 9.8 MXN/kg for Chino Criollo. This indicates high profit margins for the native landraces. While Saladette has an average profit margin of only 22%, Citlale has 64-76%, Ojo de Venado 63-75% and Chino Criollo 49%. One bowl is a tool of measurement for volume used in the region and measures tomatoes of approximately 200g to 350g, depending on size of the bowl and amount of tomato filled in it. For the Saladette type tomatoes a relation between number of salespersons per city and price per kg was evident. With higher number of salespersons, the price was usually lower, which is in accordance to the market theory of a reverse relation between quantity supply and price of the product.

Table V. 3. Number of salespersons and average price of selling for each landrace in the surveyed area for each city in which tomatoes are sold.

City	Citlale		Ojo de Venando		Chino Criollo	
	Number of salespersons	Price kg^{-1} (MXN)	Number of salespersons	Price kg^{-1} (MXN)	Number of salespersons	Price kg^{-1} (MXN)
Chocamán	1	8	3	8.3	0	0
Ciudad Mendoza	1	5	1	10	0	0
Córdoba	2	10	0	0	0	0
Coscomatepec	6	10	4	8.8	0	0
Cuitláhuac	0	0	1	10	0	0
Fortín	0	0	3	6.7	0	0
Huatusco	1	5	0	0	0	0
Ixtaczoquitlán	2	10	0	0	0	0
Orizaba	7	10	0	0	3	9.8
Rafael Delgado	1	10	0	0	0	0
Río Blanco	0	0	1	10	0	0
Tequila	1	8	0	0	0	0
Zongolica	2	9	1	10	0	0

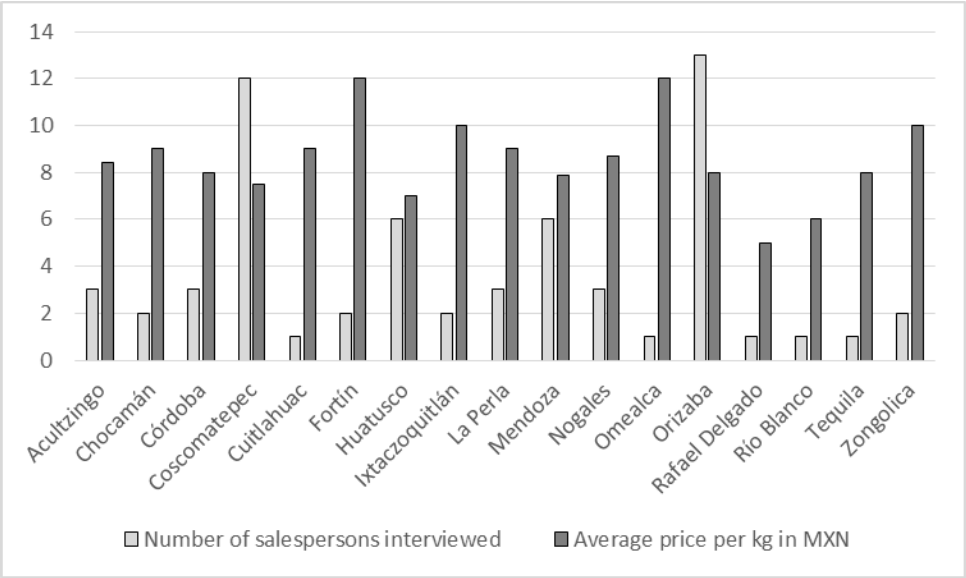

Figure V. 2. Number of salespersons and average price of selling for tomatoes of the Saladette type in the surveyed area for each city.

The quality of the tomato fruit that were offered on the markets was evaluated by visual appearance. The evaluation was based on maturity, size, impurities and damage on fruits. Fruits were rated with one (1) for best quality, large, mature fruits without damages or impurities, to five (5) for worst quality, small, over or under mature fruits with many impurities and damages. The landrace tomatoes had an overall better fruit quality compared to Saladette tomatoes. For the Citlale tomatoes 50% were rated with 1 or 2, 46% with 3 or 4 and only 4% with 5. As these fruits are offered on vine the number of unripe fruit on a vine varied widely depending on number of fruits per vine and moment of harvest. Some vines had impurities as dust, dirt or spider webs and some vines had fruits with damages, which results in completely destroyed fruits for Citlale. Similar results were obtained for Ojo de Venado with the majority of the fruits evaluated with 1 or 2 (62%) and the rest rated 3 or 4 (38%), none were rated with 5. The Ojo de Venado landrace is also offered on vine but with less fruits per vine compared to Citlale. Some fruits were offered unripe and fruit size varied widely in some cases. Impurities were comparable to those in Citlale fruits and few fruit had damages. All of the Chino Criollo tomatoes were rated with 3, the fruits had little damage and impurities but most were relatively small and some over mature. Only 20% of the Saladette tomatoes were rated with 1 or 2. A total of 73% were rated with 3 or 4 and 7% with 5. Many fruits were small and over mature and some had little to a lot of damage with impurities in form of dust, agrochemicals, fruit juice or even mold.

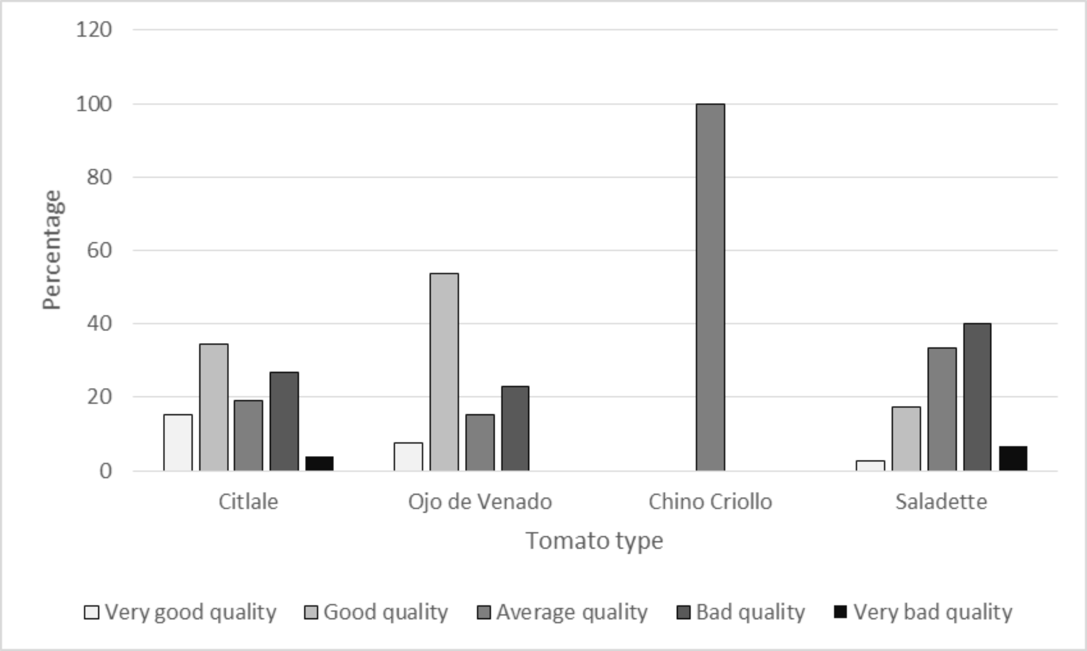

Figure V. 3. Quality of fruits presented for selling in the study region divided into five grades of quality as percentage of the total fruits evaluated for each tomato type.

There is no additional information available for tomato landrace market aspects like buying and selling volumes and prices, production quantity and time, geographical concentration of tomato landrace markets or fruit quality.

Sarukhán et al. (2009) mention that biodiversity represents the natural capital of the nation and is as much or more important than other capitals such as financial or manufactured. So we must promote and adopt a culture of its value in the context of Mexico's development. Lobato-Ortiz et al. (2012) stated that besides an in-situ conservation of native tomato landraces further action must be considered to conserve this landraces. These actions include the promotion of the use of these landraces in urban areas, promote native landraces in new markets like fair trade markets and farmers markets and the implementation of a multidiscipline team to elaborate a strategy for the implementation of post-harvest technology, package, design and strategies to commercialize the product. The EU tries to enhance the use of landraces by certain strategies, including the promotion of registration of landraces as “conservation varieties” and furthermore farmers cultivating landraces are promoting their products in different ways (Veteläinen et al., 2009). A study with Indian eggplant (*Solanum melongena* L.) landraces found that urban consumers are willing to pay a price premium for certain landraces which is a multiple of what farmers receive under current conditions in local markets and that a coexistence of modern cultivars and landraces is possible (Krishna et al., 2009). Some Italian farmers are cultivating a maize landrace, used for the traditional meal polenta, with increasing demand due to increasing consumer awareness for local and low-input production or a celery landrace highly valued by local consumers, restaurants and gourmet academies for its flavor (Lucchin et al., 2003; Torricelli et al., 2013).

V.4. CONCLUSIONS

The tomato production and market of Mexico is more diversified than existing literature is stating. The production of native landraces exists in a small scale in the High Mountains Region of Veracruz, with landraces of the types Citlale and Ojo de Venado. Fruits are sold on local markets with low distance to producers and fruits of the landrace Chino Criollo, produced in the state of Puebla, can be found on markets in the investigated region. The landrace tomatoes are sold directly by producers or sold to salespersons. The Saladette type tomatoes are by far the most bought tomato in the region and price of the landraces is higher than the Saladette price but the visual quality of the landraces is usually better. The unexplored market of native Mexican landraces of tomato may contain surprising information. Not only may the total national production of tomato be much higher than evaluated by the Mexican information service for agrifood and fishery (SIAP) that do not account for landraces but also a lot more diversified. Our investigation is proof of an appreciation of fruit characteristics of these landraces by the consumers and by demanding the product the landrace is conserved in the region and thus increasing biodiversity and protecting this biological heritage. Compared with recognition and appreciation of heirloom tomatoes in the US and Europe, the Mexican landraces are unpopular or even unknown. As production occurs in small scale with local distribution, the producers are in need of some strategy and support to increase production and distribution to urban consumers and combine these efforts with information campaigns about the importance of landraces and marketing to point out the unique flavor and production practices.

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ANEXOS ESTADÍSTICOS

Disponible en la versión digital