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BIOLOGY

Yield analysis of *Physalis ixocarpa* Brot. ex Hornem varieties under greenhouse and field conditions

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ABSTRACT: *Physalis ixocarpa (husk tomato) is traditionally cultivated in Mexico, and nowadays the yield is low. In this study, four cultivars of husk tomato were evaluated, under greenhouse and field conditions. It was carried out a split-plot experimental design in a 4x2 factorial arrangement. The large plot was the growth conditions and the small plot was the variety. The microclimate, soil and yield variables were recorded. In the field, the Integrated Photosynthetic Active Radiation (IPAR) was higher 12mol m^{-2} d^{-1} than in the greenhouse. The average temperature was slightly higher 1.18°C in the greenhouse and the average relative humidity was slightly higher 0.89% in the field. Plants grown in the greenhouse had lower negative values for the matric potential of the soil. Water consumption and water use efficiency were 10.31 and 53.43% higher in the greenhouse that in the field, respectively. The number of fruits and yield increased significantly in all varieties grown under greenhouse conditions.*
Key words: *horticulture, husk tomato, intensive production, Solanaceae, yield.*

Análise de rendimento das variedades *Physalis ixocarpa* Brot. ex Hornem sob condições de estufa e de campo

RESUMO: *A Physalis ixocarpa (Tomate de cáscara) é cultivada tradicionalmente no México. Entretanto, sua produtividade de frutos é considerada baixa. Neste estudo, avaliou-se quatro cultivares de Physalis ixocarpa cultivadas em ambiente protegido e a céu aberto. O delineamento experimental utilizado foi em blocos ao acaso no esquema de parcelas subdivididas com arranjo fatorial 2x4. Foi alocado na parcela principal o fator ambiente de cultivo e na subparcela o fator cultivar. Foram analisadas variáveis climáticas de solo e a produtividade de frutos. A radiação fotossinteticamente ativa integrada (RFAI) no ambiente a céu aberto foi maior em 12mol m^{-2} dia^{-1}, em relação ao ambiente protegido. A temperatura média foi ligeiramente maior em 1,18ºC no ambiente protegido e a umidade relativa foi ligeiramente maior em 0,89% a céu aberto. Os valores negativos do potencial mátrico do solo foram mais baixos no ambiente protegido. O consumo e a eficiência do uso da água foram, respectivamente, 10,31 e 54,43% maiores no ambiente protegido, em relação ao ambiente a céu aberto. O número e a produtividade de frutos incrementaram, significativamente, em todas as variedades avaliadas nas condições de ambiente protegido.*
Palavras-chave: *horticultura, Physalis ixocarpa, produção intensiva, Solanaceae, produtividade.*

INTRODUCTION

Green tomato, tomatillo or husk tomato (*Physalis ixocarpa* Brot. ex Hornem) is a highly-demanded native vegetable from Mesoamerica. For the last three years, the husk tomato has been the fifth most economically important vegetable in Mexico. Most production is carried out by small farmers in less than one hectare plots. In 2014, the total cultivated surface was of 44,000ha; their yield was 20t ha^{-1} under irrigation and 14t ha^{-1} under rain fed conditions (SAGARPA, 2016). Nonetheless, these yields are considered low and they could possibly increase by applying technologies such as greenhouses (LOPEZ-LOPEZ et al., 2009). The limitations for commercial greenhouse production of husk tomato: adequate greenhouses designed to meet the requirements for these species, and decent availability of varieties adapted to this production system (SANTIAGUILLO et al., 2009 and PONCE et al., 2012). As these authors pointed out, greenhouse production of husk tomato is a viable option due to market forces and to provide protection from ambient conditions such as extreme cold temperatures. RAMOS et al. (2002) obtained maximum yields of husk tomato grown under greenhouse conditions of 2.52kg m^{-2} by using the CHF1-Chapingo genotype; SANTIAGUILLO et al. (2004) reported yields of 42.5t ha^{-1} when they cross-pollinated genotypes CHF1-Chapingo and Verde Puebla. However, PEÑA-LOMELI et al. (2014) reported that genotypes derived from the Rendidora variety yielded more under both conditions. In the last

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five years in Mexico, prices of commercial varieties of *Physalis* spp., for field-sowing, like Verde Puebla and Rendidora are similar and sometimes higher, than the price for *S. lycopersicum* L.; native species of *Physalis* spp. can triple that price. During periods when tomato prices are high, husk tomato (native or improved) is used as a substitute (VARGAS et al., 2015). Based on these facts, this research compared the yield response of four *Physalis* spp. varieties sowed in the field and under greenhouse.

MATERIALS AND METHODS

The experiment was conducted from September 18th, 2015 to February 7th, 2016 at Santa Cruz Xoxocotlán, Oaxaca, México. This place is located at 1530m above sea level, 17° 1’ 31” N, and 96° 43’ 11” W. Four husk tomato varieties, Tecozautla, Rendidora, Diamante and San Martin were germinated in 200-well polystyrene trays filled with 80% Sphagnum peat moss and 20% Agrolite. Trays were watered daily with water containing 75, 20 and 75mg L^{-1} of N, P and K, respectively. Seedlings were transplanted to the field and to the greenhouse 30 days after germination (October 18th). Plant density was 1.5 plants m^{-2} in 1mx23mx0.30m (WxLxH) rows. Every row was covered with black and silver plastic.

Physical properties of the soil were analyzed by following the Official Mexican Norm Standard NOM–021-RECNAT-2000 (SEMARNAT, 2016). The soil had a sandy texture (91% sand, 2.7% litmus and 6.3% clay), an apparent density of 1.55g cm^{-3}, a field capacity of 8.5, a wilting point of 3.5%, and a basic filtration of 6.3cm h^{-1}. Irrigation was provided with ribbons and droppers at a flow of 1L h^{-1} and a pressure of 0.8kg cm^{-2}. Nutritive solution was implemented according to URRESTARAZU (2004). The concentration in mg L^{-1} of each element was as follow: N (250), P (60), K (300), S (200), Mg (75), Fe (3), Mn (0.5), B (0.5), Cu (0.1) and Zn (0.1). Soil humidity was monitored daily by a tensiometer placed in the center of the experimental area of the greenhouse and the field (Irrometer®SR, Irrometer Company, Riverside California, USA) according to the VILLALOBOS et al. (2004) method, and irrigation was applied when needed. Likewise, the water consumed was determined by the volumetric method cited by this author, measuring the volume of water applied through irrigation during the growing period. The water-use efficiency was calculated according to FLORES et al. (2007), OJODEAGUA et al. (2008) y HASHEM et al. (2011), as the ratio between yield (kg) to the total amount water (m^3) use during the crop cycle.

A tunnel-type greenhouse, covered with 200 µm thick transparent plastic was used. Ventilation was passive by using hand-powered windows: one towards the Zenith and two on the sides. Side windows allowed the entrance of bees and insects into the greenhouse. The field plot had the same dimensions as the greenhouse. An *Apis mellifera* beehive was placed outside the greenhouse to promote pollination according to PEÑA- LOMELI et al. (2014).

Temperature and relative humidity of the air was recorded at both conditions with Hobo Pro V2 data loggers (Onset®, Massachusetts, USA). Photosynthetically Active Radiation (PAR, µmol m^{-2} s^{-1}) was measured inside and outside the greenhouse, two sunny days every week, throughout the crop cycle. PAR readings were taken every hour from 8:00 to 18:00h by using a MQ-300 linear quantum sensor (Apogee® Instruments Inc. UT, USA). With the average hourly values of the PAR, the Integrated Photosynthetic Active Radiation (IPAR) was calculated according to FAUST (2002), because plant growth is determined in mol m^{-2} day^{-1} (KORCZYNSKI et al., 2002).

A split-plot experimental design was carried out in a 4x2 factorial arrangement with three replicates. The big plot was “the condition” (field and greenhouse), and the small plot was “a husk tomato variety” (Rendidora, Tecozautla, Diamante and San Martin). Each experimental unit was made up of four plants. Seven harvests were made, from December 10th, 2015 to February7st, 2016. Fruits were counted, weighted on a digital scale (O’Haus Pionner® Corporation, USA), and measured on their equatorial diameter (according to the norm NMX-FF-054-1982, for size and equatorial fruit diameter). Shoot thickness was measured with a digital caliper (Series 500, Mitutoyo® USA) and branch length was measured with a measuring tape (Stanley®).

Analysis of variance and Tukey’s mean comparisons ($P \leq 0.05$) were analyzed on each variable by using the SAS® software version 9.0 (STATISTICAL ANALYSIS SYSTEM, 2002).

RESULTS AND DISCUSSION

Microclimate comparison

Data showed significant differences, from 8:00 to 18:00h, between PAR inside and outside the greenhouse. The highest PAR occurred at 13:00h with 1700µmol m^{-2} s^{-1} inside the greenhouse and 2250µmol m^{-2} s^{-1} outside the greenhouse. *P. ixocarpa*

Brot. ex Hornem plants cultivated in the field and in the greenhouse received an IPAR in average 42 and 30mol m^{-2} d^{-1}, respectively (Table 1). In the greenhouse was less than on the field due of the plastic covering. For the whole trial, PAR values followed this behavior, yet the lowest values surpassed the minimum required values for this vegetable (19μmol m^{-2} s^{-1}).

In the field *P. ixocarpa* Brot. ex Hornem plants received higher IPAR than those grown under the greenhouse (Table 1). Average monthly temperature and relative humidity under the greenhouse and on the field are shown in table (1). Temperatures in the greenhouse had an increase of 0.53 to 1.92°C with respect to the field; because inside the greenhouse the airflow is less due to the obstruct for plastic cover or mesh (VALERA et al., 2006). ADAMS et al. (2001) indicated that an increase in greenhouse temperature promotes growth, flowering and fruit production in tomato (*Lycopersicum esculentum L.*), and hinders attacks by pests and diseases (RODRÍGUEZ et al., 2011). Conversely, in October the average relative humidity was lower in the greenhouse with respect to the field, due to the higher temperature under the plastic cover (BURIOL et al., 2000).

Matric potential of the soil, water consumption and water use efficiency

Significant differences were reported in each variable for field and greenhouse conditions. Greenhouse soil reached the maximum negative value for matric potential, -24kPa average, whereas this value was -20kPa on the field (Figure 1). During the crop cycle, in the greenhouse were consumed 84L $plant^{-1}$; while 75.3L $plant^{-1}$ were consumed in the field (Figure 2), which was 10.36% lower compared to the greenhouse, due to the increase in temperature and decrease in relative humidity (Table 1), this also to the greater number of fruits and yield (Table 2 and 3).

Water-use efficiency was 38.46kg m^{-3} in the greenhouse, while in the field it was 17.91kg m^{-3} (Figure 2), this due to high temperature and low relative humidity of the environment (Table 1).The greenhouse result in this study it was 28.13% higher than LOPEZ-LOPEZ et al. (2009) whose reported values of water-use efficiency of 27.64kg m^{-3} when grown on plastic-covered fields. Plants grown at greenhouse had lower negative values for the matric potential of the soil. WANG et al. (2006) and ZHANG et al. (2011) indicated that water demand by any crop is tightly related to environmental factors, such as air temperature, radiation, and wind, that increase evapotranspiration in plants (HASHEM et al., 2011).

Yield and its components

Significant differences ($P \leq 0.05$) were reported for the varieties, conditions and the interaction between factors for the variables number of fruits per plant, total yield, equatorial diameter, and fruit weight (Table 2). The highest number of fruits (115.67) was collected in the greenhouse; Rendidora had the highest number of fruits, followed by Diamante, Tecozautla and San Martin. The lowest number of fruits (34.33) and the total yield was collected from the Tecozautla variety under field conditions. Rendidora, variety had the highest yield (4.84kg m^{-2}) under greenhouse conditions. Tecozautla variety produced type B fruits (4.7-5.4cm, based on the NMX-FF-54-1982 standard), under field and greenhouse conditions. The mean fruit size was 4.9cm

Table 1 - Climate conditions for *P. ixocarpa* Brot. ex Hornem cultivated under greenhouse and field conditions for five months. Santa Cruz Xoxocotlán, Oaxaca, México. 2015/16.

Months	-----------IPAR (mol m^{-2} d^{-1})-------------		------------Temperature (ºC)-------------		---------Relative Humidity (%)---------	
	Greenhouse	Field	Greenhouse	Field	Greenhouse	Field
Oct.	34.98 ±2.51	48.98 ±2.90	22.17 ±1.77	20.25 ±0.81	66.05 ±6.45	72.93 ±7.28
Nov.	30.42 ±2.35	42.59 ±2.15	20.26 ±2.06	19.33 ±1.97	68.66 ±3.57	68.93 ±3.54
Dec.	28.9 ±1.88	40.46 ±2.56	18.96 ±1.42	18.43 ±1.33	66.19 ±2.71	65.36 ±2.77
Jan.	27.38 ±2.10	38.33 ±2.24	18.01 ±2.11	16.86 ±2.04	56.23 ±4.95	54.49 ±5.69
Feb.	28.32 ±2.35	39.65 ±1.89	20.77 ±1.45	19.35 ±1.13	55.09 ±4.06	54.92 ±4.76
Mean	30.0	42.0	20.03	18.85	62.44	63.33

Table 2 - Genotype by environment interaction and its effect on *P. ixocarpa* Brot. ex Hornem characteristics. Santa Cruz Xoxocotlán, Oaxaca, México. 2015/16.

Cultivar	Equatorial diameter (cm)			-----------Fruit weight (g)--------------			---------Fruit plant^{-1}----------			---Total yield (kg m^{-2})---		
	Greenhouse	Field	CV (%)	Greenhouse	Field	CV (%)	Greenhouse	Field	CV (%)	Greenhouse	Field	CV (%)
Tecozautla	4.41 B[1]a[2]	4.90 Aa	8.08	41.65 Ba	52.29 Aa	20. 89	79.67 Ab	34.33 Bc	30.38	4.06 Ab	2.73 Ba	27.91
Rendidora	4.16 Ab	3.84 Bc	3.75	30.46 Ab	26.10 Bc	5.02	115.67 Aa	58.00 Ba	8.64	4.84 Aa	2.10 Bb	10.66
Diamante	4.21 Aab	4.24 Ab	8.21	34.68 Ab	35.19 Ab	22. 22	81.67 Ab	62.00 Ba	19.04	3.95 Ab	2.73 Ba	12.29
San Martin	3.99 Ab	4.22 Ab	4.94	32.39 Bb	37.29 Ab	22. 04	78.00 Ab	49.33 Bb	29.47	3.07 Ac	2.40 Bab	23.94
CV (%)	6.9	6.6		22.14	38.71		22.03	19.06		27.35	28.56	

[1]Uppercase letters for row analysis, [2]Lower-case letters for column analysis; [1 and 2]Same case letter in each column or row are not statistically different, Tukey ($P \leq 0.05$); CV: coefficient of variation.

and 52.29g for the field grown plants, and 4.41cm and 41.65g for the greenhouse plants. Varieties Diamante, San Martin and Rendidora produced size C fruits (3.9 to 4.6cm in equatorial diameter, based on the NMX-FF-54-1982 standard).

Harvests and production precocity

Total yield from the seven harvests from the *P. ixocarpa* Brot. ex Hornem plants showed significant differences ($P \leq 0.05$) among varieties and conditions (Table 3). Rendidora under field and greenhouse

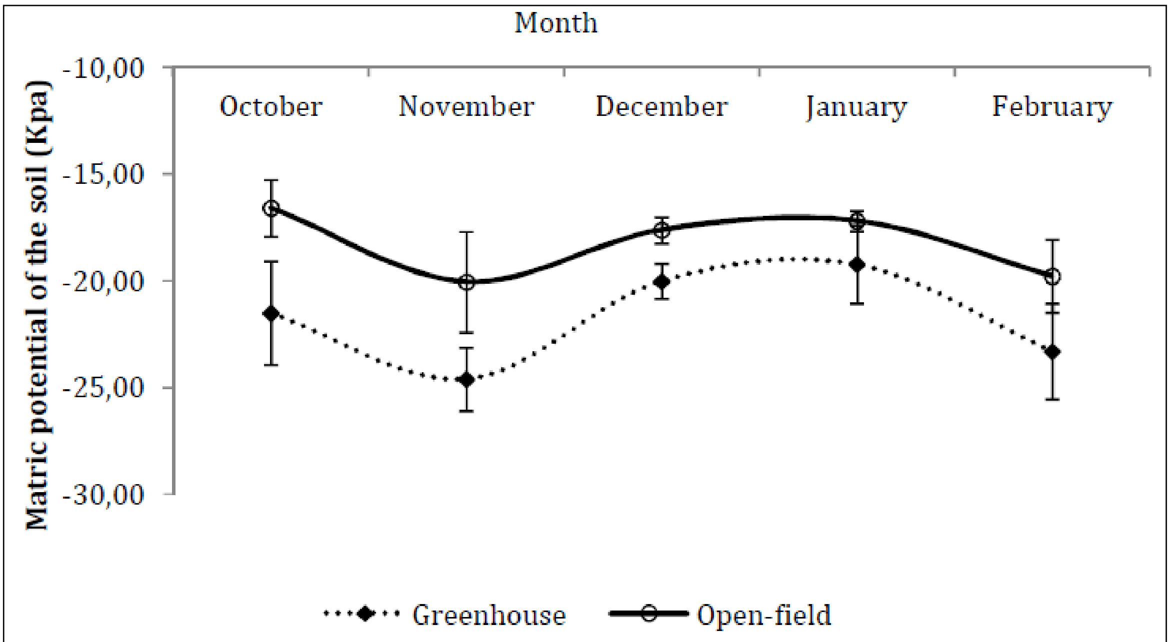

Figure 1 - Monthly average of matric potential of soil under greenhouse and field conditions. Santa Cruz Xoxocotlán, Oaxaca, México. 2015/16.

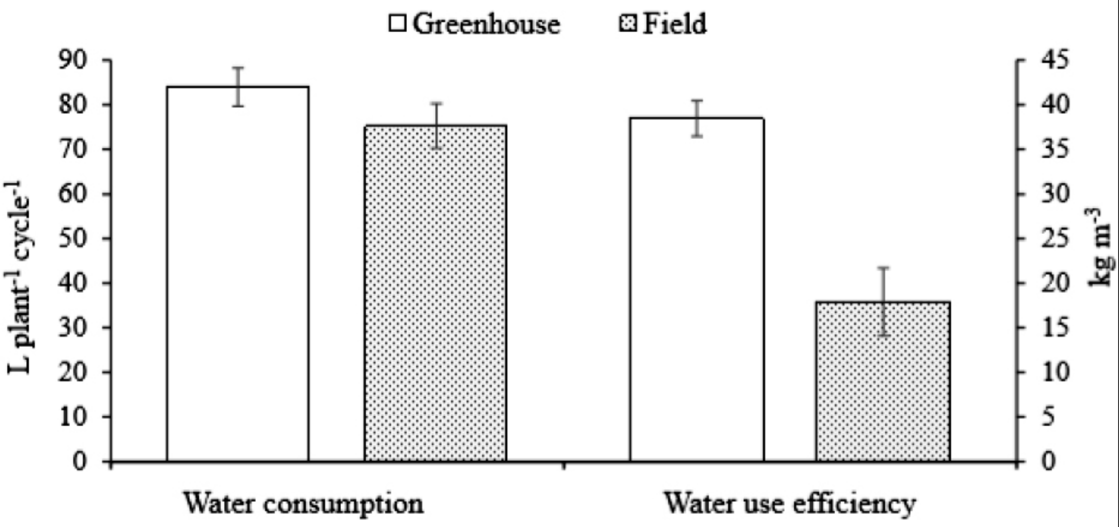

Figure 2 - Water consumption and Water Use Efficiency of *P. ixocarpa* Brot. ex Hornem varieties grown under greenhouse and field conditions. Santa Cruz Xoxocotlán, Oaxaca, México. 2015/16.

conditions produced the first fruit at 49 days after transplant (DAT). This characteristic is desirable since harvests could be earlier, and possibly more cycles per year could be grown as SÁNCHEZ & PONCE (1998) established for *S. lycopersicum* L. The San Martin produced fruits 57 DAT on the field and 63 DAT in the greenhouse; this variety is considered a late-producer for field or greenhouse production. The yield reached its peak for the Rendidora at 70 DAT under both conditions; meanwhile, Tecozautla reached it at 63 DAT in the field and at 70 DAT in the greenhouse. Peak production for the San Martin was reached at 70 DAT in the greenhouse and the field. The highest yield for the four varieties and both conditions were obtained from the third to the sixth

Table 3 - Average yield patterns in four *P. ixocarpa* Brot. ex Hornem varieties grown under greenhouse and field conditions for seven harvests. Santa Cruz Xoxocotlán, Oaxaca, México. 2015/16.

Variety	Days after transplant							Total
	49	57	63	70	77	100	113	
	Greenhouse (kg m^{-2})							
Tecozautla	0.01 a[1]	0.11 b	0.62 b	0.98 b	0.60 b	1.23 a	0.52 a	4.06 b
Rendidora	0.05 a	0.23 a	0.79 a	1.55 a	0.82 b	0.79 b	0.62 a	4.84 a
Diamante	-	0.11 b	0.60 b	0.77 b	1.36 a	0.55 bc	0.56 a	3.95 b
San Martín	-	-	0.53 b	1.05 b	0.78 b	0.40 c	0.30 b	3.07 c
CV (%)	7.22	30.21	10.87 a	19.63	9.51	13.02	23.74	9.12
	Field (kg m^{-2})							
Tecozautla	-	0.53 a	0.91 a	0.51 b	0.51 a	0.51 a	0.06 c	2.73 a
Rendidora	0.03 a	0.38 ab	0.49 b	0.41 bc	0.27 b	0.27 b	0.18 b	2.10 b
Diamante	0.04 a	0.21 bc	0.56 b	0.30 c	0.56 a	0.56 a	0.44 a	2.73 a
San Martín	-	0.10 c	0.54 b	1.03 a	0.46 a	0.46 a	0.24 b	2.40 b
CV (%)	4.35	22.78	21.10	10.35	19.75	19.75	26.37	9.52

[1]Same letter in each column is not statistically different, Tukey (P≤0.05); CV: coefficient of variation.

harvest. These results differ from PONCE et al. (2012) and PEÑA-LOMELI et al. (2014). They reported that the highest yield was obtained from the first harvest in the field and in the greenhouse. Contrary to PEÑA et al. (1997), the optimal period between harvests reported in this research should be similar, instead of 21 days. The Diamante was reached its peak production in the greenhouse at the 77 DAT, similar to the results reported by PEÑA et al. (1997).

CONCLUSION

The microclimate of the greenhouse with respect to the field favored a greater yield in all varieties of *P. ixocarpa* Brot. ex Hornem. Plastic covering, combined with side windows opened during the day, modified the microclimate, reduced the PAR and consequently the IPAR, and the temperature was slightly higher. This favored the efficient use of water and increased the number of fruits and yield**.**

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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