Ciência Rural, Santa Maria, v.51:1, e20200992, 2021 http://doi.org/10.1590/0103-8478cr20190992

ISSNe 1678-4596
CROP PRODUCTION

Plant density on yield of Husk tomato (*Physalis ixocarpa* Brot.) in field and greenhouse

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ABSTRACT: *Physalis ixocarpa Brot. (tomatillo or Husk tomato) is one of the five major vegetables cultivated in Mexico, but its yield in the field is low. However, greenhouse crops and the enhancement in plant density can promote an increase in yield per area. The aim of this research was to evaluate: yield, water consumption and water use efficiency of variety husk tomato 'Diamante'. The experiment was conducted under field and greenhouse conditions, during the two crop cycles (autumn-winter and spring-summer), with different planting densities (1.5, 2 and 3 plants m^{-2}), in complete random blocks and three replications. The yield was influenced by the planting density and environments. In both environments, the planting density, with 3 plants m^{-2} increased yield 32 %, and 25% in water use efficiency (WUE). In greenhouse increased 32% yield m^{-2} and the WUE it was 18.1 kg m^{-3} while in the field was 16.4 kg m^{-3}. Crop cycle spring-summer produced differences of 27% in plant length and 15% in stem diameter, probably due to the temperature that was 4 ºC higher with respect to autumn-winter.*
Key words: *Diamond variety, horticultural crops, tomatillo, water use efficiency.*

Densidade vegetal no rendimento de tomate Husk (*Physalis ixocarpa Brot.*) em campo e casa de vegetação

RESUMO: *Physalis ixocarpa Brot. (tomatillo ou tomate de cáscara) é um dos cinco principais vegetais cultivados no México, mas seu rendimento no campo é baixo. No entanto, as culturas em estufa e o aumento da densidade das plantas podem promover um aumento no rendimento por área. O objetivo desta pesquisa foi avaliar: rendimento, consumo de água e eficiência no uso da água do tomate de casca de variedade 'Diamante'. O experimento foi conduzido em condições de campo e casa de vegetação, durante os dois ciclos de cultivo (outono-inverno e primavera-verão), com diferentes densidades de plantio (1,5, 2 e 3 plantas m^{-2}), em blocos aleatórios completos e três replicações. O rendimento foi influenciado pela densidade e pelos ambientes de plantio. Nos dois ambientes, a densidade de plantio, com três plantas m^{-2}, aumentou a produtividade em 32% e em 25% na eficiência no uso da água (WUE). Em casa de vegetação aumentou 32% do rendimento m^{-2} e o WUE foi de 18,1 kg m^{-3}, enquanto no campo foi de 16,4 kg m^{-3}. O ciclo da safra primavera-verão produziu diferenças de 27% no comprimento das plantas e 15% no diâmetro do caule, provavelmente devido à temperatura 4 ºC maior em relação ao outono-inverno.*
Palavras-chave: *Variedade de diamantes, culturas hortícolas, tomatillo, eficiência no uso da água.*

INTRODUCTION

Husk tomato (*Physalis ixocarpa* Brot.) is one of the most important crops for Mexican gastronomy; and therefore, for the vegetable sector of Mexico. It occupies fifth place in production volume and fourth in cultivated area (SIAP, 2018), after the following vegetables: chili (*Capsicum annuum* L.), potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicon* L.) and onion (*Allium cepa* L.). In 2018, the cultivated area was 41,336 ha with a yield of 19 t ha^{-1} (SIAP, 2018). This yield is considered low due to inefficient water management (LÓPEZ-LÓPEZ et al., 2008), environmental factors and pests and diseases (SANTIAGUILLO-HERNÁNDEZ et al., 2009), and because there is a lack of research in protected production agriculture systems (REIS et al., 2013; PEÑA-LOMELÍ et al., 2014; ARAUJO et al., 2016). There are also few studies on plant densities among other determining factors, that could possible increase yield and obtain the potential yield of 83.8 t ha^{-1} mentioned by SOLDEVILLA-CANALES et al. (2002) for this crop.

In protected agriculture systems, it is of fundamental importance to determine plant or sowing density (VILLALOBOS et al., 2009) because is related to the number of plants or seeds to establish in a given area when the plantation frame or topological design varies and yield (PAPADOPOULOS & ORMROD, 1990; AMUNDSON et al., 2012; PEÑA-

Received 12.14.19 Approved 07.31.20 Returned by the author 09.02.20
CR-2020-0992.R1

LOMELÍ et al*.,* 2014). Moreover, the species, variety, growth habit, climate, water availability, type of soil and production aim should be considered in order to use the available space efficiently and facilitate cultivation tasks such as weeding fumigation, training, pruning and harvest (VILLALOBOS et al., 2009; BARROSO et al., 2017).

The microclimate, fertilization and election of the suitable plant density favors interception of solar energy (HEUVELINK & GONZÁLEZ-REAL, 2008), increases yield and irrigation water use efficiency (QIU et al., 2013). However, a higher plant density increases water consumption, and so it is necessary to assure the irrigation water supply especially during flowering. SILVA et al. (2019) mentioned low tomato yield (*Solanum lycopersicon* L.) when irrigation is suspended, due to abortion of flowers and fruits. CASTILLO-CÉREZ et al. (1992) obtained the highest yield and fruit quality of *P. ixocarpa* trained on trellises with 5 plants m^{-2} in the field. Under conditions of greenhouse and hydroponics, RAMOS-LÓPEZ et al. (2018) reported on *P. ixocarpa* higher yield with a density of 1.5 plants m^{-2} a yield in greenhouse 2.73 kg m^{-2}, while SOLDEVILLA-CANALES et al. (2002) obtained on *P. ixocarpa* 2.5 kg m^{-2} with a density of 3.3 plants m^{-2}, using trellises to support the plants, mulch on the soil and a supply of CO_2 to the soil. However, PEÑA-LOMELÍ et al. (2014) cultivated *P. ixocarpa* in the field and in greenhouse and obtained better results in the field with a density of 2 plants m^{-2}.

Based on these facts, this study evaluated three plant densities under field and greenhouse conditions, and their effect on water consumption, growth and productive parameters of *P. ixocarpa*.

MATERIALS AND METHODS

The study was conducted in Santa Cruz Xoxocotlan, Oaxaca, Mexico (17° 1' 31" N and 96° 43' 11" W, altitude 1518 m), during the autumn-winter (AW-2016-2017) and spring-summer (SS-2017) growing cycles. We used the husk tomato variety 'Diamante' (hybrid obtained from the variety CHF1 Chapingo and Puebla SM3, by Universidad Autónoma Chapingo, Mexico with registration TOM-002-170908 in CNVV- SNICS-SAGARPA). This early semi-erect variety produces large bright green fruits (with three locules); it is medium firm and has a short shelf life. Seeds are brownish-yellow, and when it is cultivated with irrigation and mulch, it can produce 30 t ha^{-1} (PEÑA-LOMELÍ et al., 2018).

Seeds were germinated in polystyrene trays with 200 cavities 18.7 cc volume. We used a mixture of 3:1 v/v of the organic substrate Sunshine Mix-3 (Sun Gro® Horticulture, MA, USA) and agrolite (Agrolita® de México S.A. de C.V.).

Water and soil at the site were analyzed in accordance with the Official Mexican Norm NOM–021-RECNAT-2000 (SEMARNAT, 2003). The physical properties of the soil were the following: sandy texture, bulk density 1.55 g cm^{-3}, field capacity 8.5%, wilting point 3.5%, basic infiltration 6.3 $cm \cdot h^{-1}$ and organic matter 1.6%. Results of the chemical analysis were pH 7.6, macro-elements (mg kg^{-1}): N (12), P (92), K (142), Ca (4318), Mg (350) and SO_4 (253), and microelements (mg kg^{-1}): B (2.0), Cu (4.4), Fe (211), Mn (90), Zn (3.2) and Na (195). Analysis of the water revealed pH 7.82 and CE 0.85 dS m^{-1}, macro-elements (meq L^{-1}) Ca (4.51), Mg (1.56), K (0.05), SO_4 (1.18), NO_3 (1.60), and microelements (mg L^{-1}) B (0.31).

Fertigation was delivered through a drip tape with emitter's 0.20 m apart, flow of 1.9 L h^{-1} and operation pressure of the system at 1.5 kg cm^{-2} (HERRERA et al., 2013). The nutritive solution used was adjusted to that recommended by URRESTARAZU (2004) for tomato (*Solanum lycopersicon* L.) and RAMOS-LOPEZ et al. (2018) for husk tomato (*P. ixocarpa*) taking the soil and water analyses into account.

The volume of irrigation water supplied was measured with the volumetric method (VILLALOBOS et al., 2009). The total irrigated volume in each crop cycle was divided by the area of each environment and the water spending was obtained in L m^{-2}, divided by the plant density to determine the amount in liters applied to each plant (RAMOS-LÓPEZ et al., 2018). Water use efficiency (WUE) of the plants expressed in kg m^{-3} (DROOGERS & KITE, 1999).

The crop was established in two environments: field and greenhouse. A greenhouse, covered with 200 μm thick transparent polyethylene. 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 (RAMOS-LÓPEZ et al., 2018). The field plot had the same dimensions as the greenhouse. A beehive (*Apis mellifera*) was placed according to RAMOS-LÓPEZ et al. (2018). In both environments, we established four crop beds (1 x 23 x 0.30 m) in the soil with bicolor silver-black plastic mulch. The distance between beds was 2.5 m (Figure 1). In the autumn-winter cycle seedlings were transplanted to field crop beds on October 18, 2016 and in the spring-summer cycle on May 13, 2017 (in

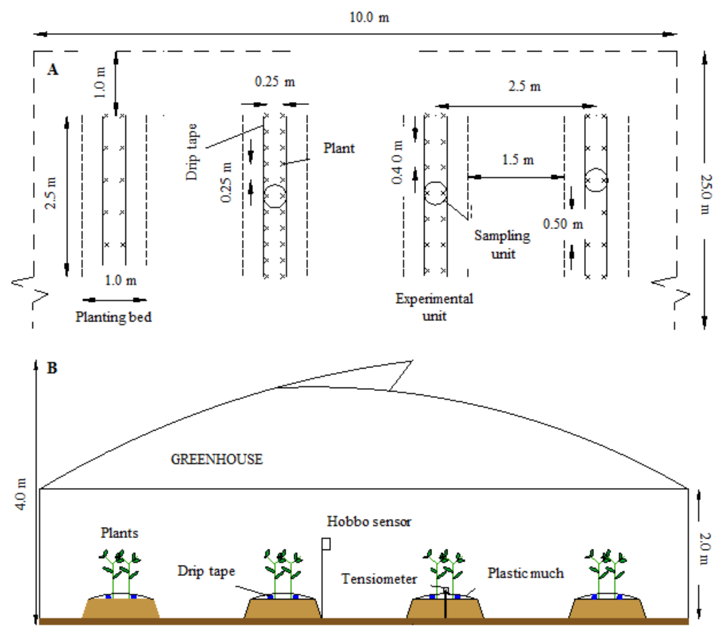

Figure 1 - Husk tomato in open-field and greenhouse. A) plant spatial distribution, B) front view. Santa Cruz Xoxocotlan, Oaxaca, Mexico. 2016/17.

both crop cycles, after 30 days of sowing). We tested three plant densities (1.5, 2 and 3 plants m^{-2}) in double rows 0.25 m apart and 0.25, 0.40 and 0.50 m between plants. The plants were not tutored (supported), and the branches grew horizontally, eventually covering the area between beds. The experiment was a complete randomyzed block design with three replications. The experimental unit consisted of 10 plants.

Temperature and relative humidity of the air were recorded with a HOBO U23 Pro v2 Temperature/Relative Humidity Data Logger (HOBO® PRO V2 ONSET, MA, USA) placed 1.20 m above soil level (four devices distributed inside and four outside the greenhouse); these data were recorded every five minutes (Figure 2).

In both environments, soil moisture was monitored daily by tensiometers placed in the soil 0.15 and 0.30 m deep (VILLALOBOS et al., 2009), was maintained between -10 and -30 kPa (THOMPSON et al., 2006). Fruits were picked when they reached physiological maturity, that is, when the fruit had a lime green color and filled and broke the calix (Figure 3E), seven harvests were made.

The morphometric variables were: plant length (Black & Decker Stanley metal flex meter), stem diameter (at the middle part of the first branch), equatorial diameter and length of fruit, measured with a digital vernier (Mitutoyo 500-473 Il, USA). Plant length and stem diameter were registered after the last picking, and fruit equatorial and longitudinal diameters at each picking. Fruits were counted, weighted on a digital scale (O'Haus Pionner® st Corporation, USA), and measured on their equatorial diameter (according to the norm NMXFF-054-1982, for size and equatorial fruit diameter). Total yield per plant was obtained from the sum of the seven pickings, dividing weight of fruits from each picking by the number of plants per experimental unit, then multiplying by plant density to convert to yield per unit of area.

The data obtained were subjected to analysis of variance and means compared by Tukey's test ($P \leq 0.05$) using the statistical software SAS® version 9.0 (SAS, 2002), and graphs were constructed using Microsoft® Excel.

RESULTS AND DISCUSSION

The comparison of means ($P \leq 0.05$) showed that the increase in plant density of 1.5 to 3 plants m^{-2} reduced yield per plant by 34%. However, the yield per m^{-2} increased 25% due to the larger number of plants (Table 1). The same behavior was reported for *P. ixocarpa* var. Rendidora and Tecozautla (RAMOS-

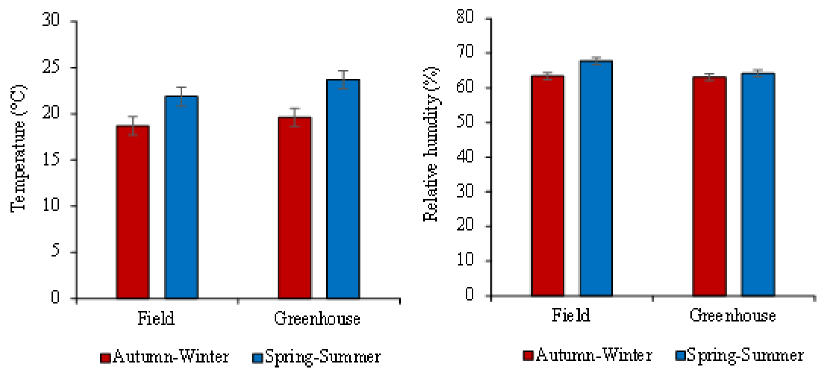

Figure 2 - Average air temperature and relative humidity during crop cycle of Husk tomato in two environments. Santa Cruz Xoxocotlan, Oaxaca, Mexico. 2016/17.

LÓPEZ et al., 2017, 2018), for *Solanum lycopersicon* L. (QIU et al., 2013) and *Persea americana* Mill. (MENZEL & LAGADEC, 2014). In this regard, GLIESSMAN (2002) mentioned that plants compete for space, water, light and nutrients, and this competition is manifested by reductions in plant growth and yield. Therefore, the lower the density the better the source/demand relationship, which

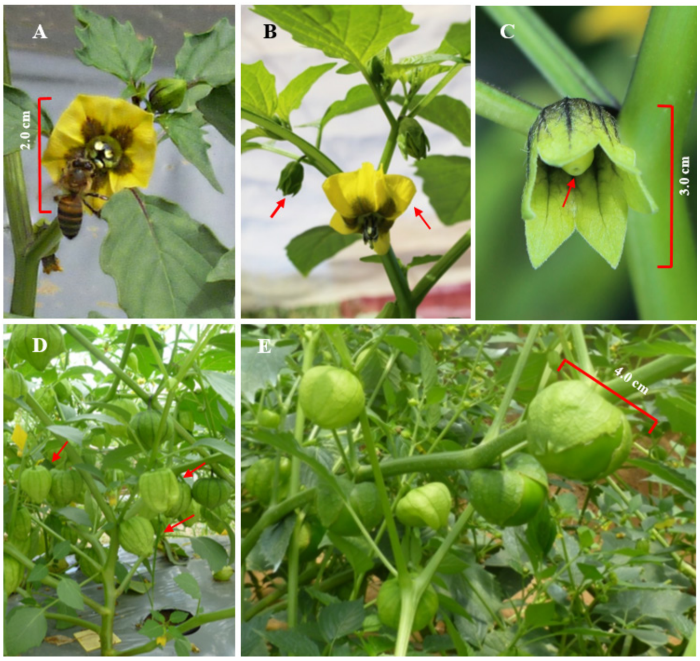

Figure 3 - Flower and fruit of *P. ixocarpa* Brot. A) *Apis mellifera* pollinating a full expanded and mature flower. B) Flower bud and open flower with corolla upwards to expose the stamens and stigma. C) Young fruit inside the calyx (husk). D) Fully developed chalice (serves to protect the fruit during its growth). E) Mature fruits, can be harvested when the calyx becomes disruption. Santa Cruz Xoxocotlan, Oaxaca, Mexico. 2016/17.

Table 1 - Effect of plantation density, environments and crop cycles on productive characters, growth and water use efficiency of ***P. ixocarpa***. Santa Cruz Xoxocotlan, Oaxaca, Mexico. 2016/17.

	PL cm	SD cm	WUE kg m^{-3}	---Fruits--- FW g	ED cm	LF cm	---Yield--- kg plant^{-1}	kg m^{-2}
---Plant density---								
1.5	152.87 a	1.46 a	14.80 b	31.18 a	4.12 a	3.30 a	2.42 a	3.64 b
2	150.71 a	1.34 b	17.41 ab	28.43 a	3.96 a	3.19 a	2.10 ab	4.20 b
3	139.97 a	1.21 c	19.66 a	31.17 a	4.01 a	3.28 a	1.60 b	4.81 a
DMS	31.44	0.20	4.24	6.48	0.21	0.22	0.52	1.08
---Environment---								
Field	123.85 b	1.37 a	16.41 a	29.90 a	4.00 a	3.26 a	1.75 b	3.63 b
Greenhouse	171.84 a	1.30 a	18.17 a	30.62 a	4.07 a	3.25 a	2.34 a	4.80 a
DMS	21.19	0.13	2.86	4.37	0.11	0.15	0.35	0.72
---Crop cycle---								
Autumn-Winter	130.00 b	1.24 b	17.33 a	30.29 a	4.10 a	3.26 a	1.94 a	3.98 a
Spring-Summer	165.69 a	1.43 a	17.25 a	30.23 a	3.96 a	3.25 a	2.15 a	4.45 a
DMS	21.19	0.13	2.86	4.37	0.21	0.15	0.35	0.72

PL: Plant length; SD: Stem diameter; WUE: Water use efficiency; FW: Average fruit weight; ED: Equatorial diameter of fruit; LF: length of fruit; DMS: Significant minimum difference. Means followed by the same letter in the columns do not differ at 0.05 significant level by Tukey test.

produces higher yield per plant, similar to the yield obtained in *Physalis ixocarpa* by RAMOS-LÓPEZ et al. (2018). In our study, higher plant density reduced stem diameter by 17%, probably because of greater competition for light among plants (GLIESSMAN, 2002). In this respect, MIELKE & SCHAFFER (2010) mentioned that the reduction in stem diameter could be due to lower interception of light, which is directly related to photosynthetic activity. Conversely, higher plant density increased water use efficiency (25%), which means an increase of five kilograms of fruit per m^{-2} similar to the water efficiency obtained in Maize by SANI et al. (2008).

Plants cultivated in greenhouse had significantly ($P \leq 0.05$) longer plants (38%) and higher yield per m^{-2} (32%) than the field-grown plants (Table 1). Longer plants and higher yields may be due to lower radiation inside the greenhouse than in the field and to a longer time with better climatological conditions during the day that allow the plants to carry out photosynthesis (QIU et al., 2013). Similar to the obtained under conditions of greenhouse and field in *P. ixocarpa* by RAMOS-LÓPEZ et al. (2018), SOLDEVILLA-CANALES et al. (2002) and *Solanum lycopersicum* by CARDOSO et al. (2018). Plants cultivated in spring-summer (SS) had higher values of plant length and stem diameter (Table 1), it is probably due to the 4 ºC increase in temperature with respect to autumn-winter (AW), to the rains in the field, and higher relative humidity (Figure 2).

Water consumption in the greenhouse was 84 and 100 L plant^{-1} in the AW and SS cycles, respectively (Figure 4A). Consumption of water in AW was similar to the 84 L water plant^{-1} in greenhouse obtained by RAMOS-LOPEZ et al. (2018) for *P. ixocarpa* var. Rendidora and Tecozautla. Water consumption was higher in the SS cycle when temperatures were higher and probably increased evapotranspiration inside the greenhouse (Figure 2), (HONDA et al., 2019). In the field, during the AW cycle, each plant consumed 76 L water plant^{-1}, similar to that reported by RAMOS-LOPEZ et al. (2018) for *P. ixocarpa* var. Rendidora and Tecozautla. In the AW cycle, because it rained, irrigation in the field was reduced. Rainwater was estimated taking as a reference plant water consumption during the AW cycle in each environment, plus the volume registered inside the greenhouse during the SS cycle (Figure 4A).

In both environments, when plant density increased, water use efficiency showed a positive linear trend (R^2= 0.81 and 0.84 for greenhouse and field, respectively). It reached a maximum of 29.7 kg m^{-3} in the macro-tunnel and of 18.53 kg m^{-3} in the field (Figure 4B). The increase in plant density in

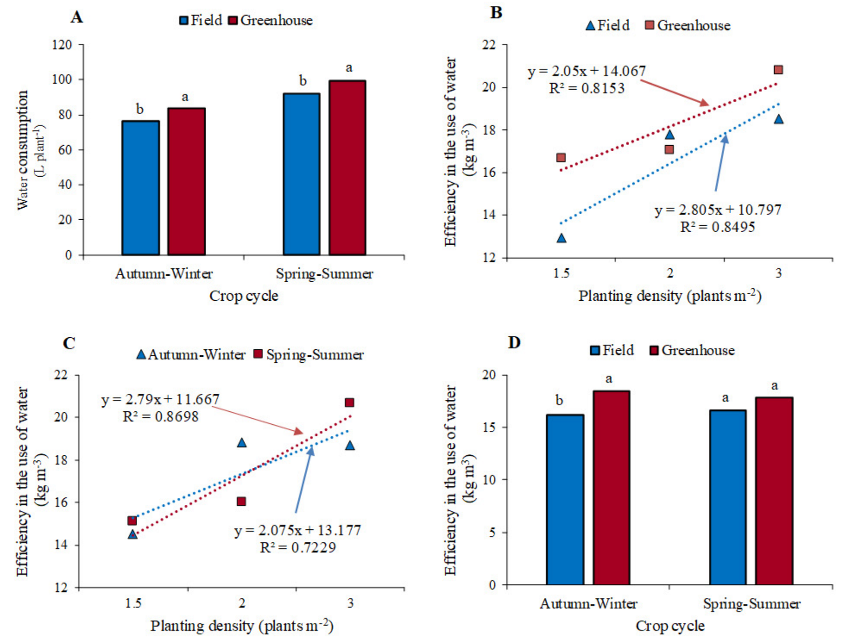

Figure 4 - A) Crop cycle and environment over water consumption. Efficiency in the use of water: B) Plant density and environment. C) Plant density and crop cycle, and D) Crop cycle and environment. Santa Cruz Xoxocotlan, Oaxaca, Mexico. 2016/17.

the two crop cycles showed an increase in WUE with a positive linear trend (R^2= 0.72 and 0.86 for AW and SS, respectively), reaching a maximum value (20.6 kg m^{-3}) in spring-summer (Figure 4C) because of the better environmental conditions for the crop in that cycle (Figure 2). The effect of crop cycle and environment on WUE (Figure 4D) was not significant. The WUE in the field was 16.4 kg m^{-3} and in the greenhouse it was 18.1 kg m^{-3}, probably the microclimate inside condition of the greenhouse favored the WUE (RAMOS-LOPEZ et al., 2017, 2018).

CONCLUSION

High planting density caused smaller stems diameter and higher yield per m^{-2} and in water use efficiency. Plant length and yield per plant and per unit of area were higher in the greenhouse, as well as the longest plant length and largest stem diameter were in the spring-summer crop cycle.

ACKNOWLEDGEMENTS

The authors grateful to the Instituto Politécnico Nacional (IPN) for the facilities to accomplish this research. As well as the Consejo Nacional de Ciencia y Tecnología (CONACyT) for the scholarship of the first author.

DECLARATION OF CONFLICTS OF 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 the final version.

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In the article "Plant density on yield of Husk tomato (*Physalis ixocarpa* Brot.) in field and greenhouse" published in Ciência Rural, volume 51, number 1, DOI http://doi.org/10.1590/0103-8478cr20200992.

In the author's, where we read:

Bernabé Ignacio López-Ramos

Read:

Bernabé Ignacio Ramos-López

Ciência Rural, Santa Maria, v.52:06, 2022 10.1590/01038478crerr20190992
e20992

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In the article "Plant density on yield of Husk tomato (*Physalis ixocarpa* Brot.) in field and greenhouse" published in Ciência Rural, volume 51, number 1, DOI http://doi.org/10.1590/0103-8478cr20200992.

In the DOI number, *where we read:*

http://doi.org/10.1590/0103-8478cr20200992

Read:

http://doi.org/10.1590/0103-8478cr20190992