

Production of specialty peppers under different protected agriculture systems

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Abstract

Peppers are a species of great importance globally; due to their nutritional contribution, the demand for this product has increased, and as a result, lines called 'specialties' have now been created. Another effect of the demand for this product, together with the new challenges presented by climate change, is the increased use of protected agriculture in all its forms; this research aimed to evaluate the production of specialty peppers under different production systems. The work consisted of using various cultivars subjected to two production environments (greenhouse and shade net). Six cultivars were used and subjected to two production systems. In conclusion, it is mentioned that the Uanj111, Uanm74, and Uanj84 cultivars adapt very well to any production system without reducing their quality.

Keywords:

Capsicum annuum L., greenhouses, production.



Introduction

Peppers (*Capsicum annuum* L.) are a crop of great importance because they are consumed worldwide, and their contributions to human health are very high. Vázquez *et al.* (2020) mention that the genus *Capsicum* is of great relevance not only for its consumption in Mexico, but also for its diversity of uses; it also stands out for its nutritional content (antioxidants and vitamin C). It is noted that production grows exponentially year after year. Recently, Mexico has positioned itself as the leading exporter of fresh peppers, with a 29% share internationally (SADER-AMHPAC, 2022).

The main buyers are countries such as the United States of America, Canada and the United Kingdom (SADER, 2024). In addition, Mexico stands out as the fourth-largest producer of this crop, with 147 808 ha used for its production and a yield of 1.75 kg m⁻² (FAO, 2022). However, the growing demand for this crop necessitates the generation of new cultivars that contribute to improving production, since it is estimated that by 2030, worldwide consumption of fresh peppers and chilies will increase from 6.3 to 8.1 Mt, which requires a 28.57% growth.

These specialty lines have gained significant importance, which is why a pepper genetic improvement process has been maintained at the national level across all breeds of this species. As a result, new cultivars have proven superior in terms of yield, tolerance to pests and diseases, environmental factors, and nutraceutical quality, which significantly improves the quality of this crop (Segovia and Romero, 2014).

The new challenges presented by agricultural production are climate change, with the rise in temperature, lack of rainfall, and increasingly frequent natural disasters; in view of that, the use of protected agriculture in all its forms is an agricultural production alternative that contributes to meeting the demand for agricultural products, also improving their quality. In 2021, the country registered 47 795 ha of area planted under cover for the production of vegetables, fruit crops and ornamental plants, an area that increases 2 700 ha year⁻¹ (SADER, 2022).

The most widely used technology is the shade net, with 44% of this area (more than 20 000 ha), followed by the greenhouse with 31% (more than 14 000 ha) and the high tunnel with 25% and a covered area of more than 12 000 ha (SADER-AMHPAC, 2022). On the other hand, by 2023, more than 16 million hectares of open-field planted area were used in Mexico, which sharply contrasts with the 6 981 062 ha harvested area (SIAP, 2023). This makes it imperative to use various systems of protected agriculture to try to mitigate or cushion the challenges, threats, and weaknesses that agricultural production currently presents.

Due to advances in the use of protected agriculture in the country, it has been selected to use improved seeds adapted to the conditions of these agricultural systems. The vast majority of seeds marketed in Mexico come from foreign companies and are very expensive; hence, there is a need to work on genetic improvement, because at present the use of national cultivars is very limited, resulting in the increased cost of improved seeds (INIFAP, 2006).

Based on this problem, a genetic improvement program for this crop was initiated in previous years in order to estimate genetic parameters useful for developing pepper (*Capsicum annuum* L.) genotypes that meet the characteristics that the market demands. The work aimed to evaluate these cultivars under different production systems and environments to determine their ability to adapt to two protected agriculture environments.

Materials and methods

The work was conducted at the Antonio Narro Autonomous Agrarian University (UAAAN), by its Spanish acronym, in Buenavista, Saltillo, Coahuila, in spring-autumn 2024. In a medium-technology multi-tunnel greenhouse covered by a 720-gauge Ginegar^{MR} Blanco polyethylene film, with extractors, wet walls, heaters and thermal control, registering a minimum temperature of 18 °C and a maximum temperature of 34 °C, and presenting an average relative humidity of 60%. In addition, a multi-tunnel shade net house covered with a black net with 35% shading will be used.

Six pepper cultivars were evaluated: a mini pepper genotype generated at the UAAAN, two jalapeño pepper cultivars also generated at the same institution, and three commercial genotypes -two peppers and one chilaca chili- (Table 1). All of them were evaluated under two environments (greenhouse and shade net house).

Table 1. Cultivars studied in a greenhouse and under a shade net house in Saltillo, Coahuila, in 2024.

Cultivars	Description
1) Uanm74	Orange mini pepper, generated at UAAAN
2) Awakino F1	Yellow California pepper
3) Uanj84	Jalapeño, generated at UAAAN
4) Uanj111	Jalapeño, generated at UAAAN
5) Xalapa	Chilaca, adapted to conditions of protected agriculture
6) Aitana F1	Red California pepper

Cultivation work

The sowing was carried out in 200-cavity polystyrene trays, which were filled with a substrate of *Sphagnum* Peat Moss (Premier Sphagnum Peat Moss®) mixed with mineral perlite (Hortiperl from Termolite®) in a ratio of 70:30, respectively. One seed was placed per cavity, and then the trays were taken to a germination chamber.

At 50 days after planting, transplantation was carried out in cultivation beds with a separation of 1.6 m and a length of 20 m; prior to transplanting, a drip irrigation system was established, and the beds were prepared with two-color (silver/black) plastic mulch, leaving the silver color exposed to solar radiation. The beds were 25 cm high, and the seedlings were established in a single row with 20 cm spacing between plants. For the crop's nutrition, water and soil analyses were carried out, and the nutrition was adjusted to the solution proposed by Steiner (1984).

Response variables

The following variables were studied: days to flowering (DTF), plant height (PH), polar fruit diameter (PD), equatorial fruit diameter (ED), total soluble solids (TSS), and total fruit yield (TFY).

Agronomic variables

To estimate DTF, the days elapsed from transplanting until the appearance of the first flower in at least 50% of the plants in each plot were counted. PH was measured with a tape measure at 120 days after transplantation (DAT), considering from the base of the stem to the apex of the plant.

Fruit quality

Fruit quality variables were estimated in the Plant Nutrition and Tissue Culture Laboratory of the Department of Horticulture of the UAAAN. To estimate the PD variable, an Autotec® digital vernier was used, considering from the base of the fruit to its apex; five fruits per cut per treatment were measured, and the average length was estimated; readings were taken in mm.

The ED was estimated using the Autotec® digital vernier to measure the middle part of the fruit in the transverse direction, taking five fruits for each treatment, and the measurements were reported in millimeters (mm). A Soonda® 0-85% refractometer was used to estimate the TSS; on it, a drop of the fruit extract was placed and covered with the cover plate and a reading on the scale of (°Brix) was taken. In the case of vitamin C content, fresh fruits were used and the AOAC (2000) methodology was employed by titration to a color change.

Yield

To estimate the TFY in kg, the weights of all fruits obtained during the production cycle were added.

Statistical analysis

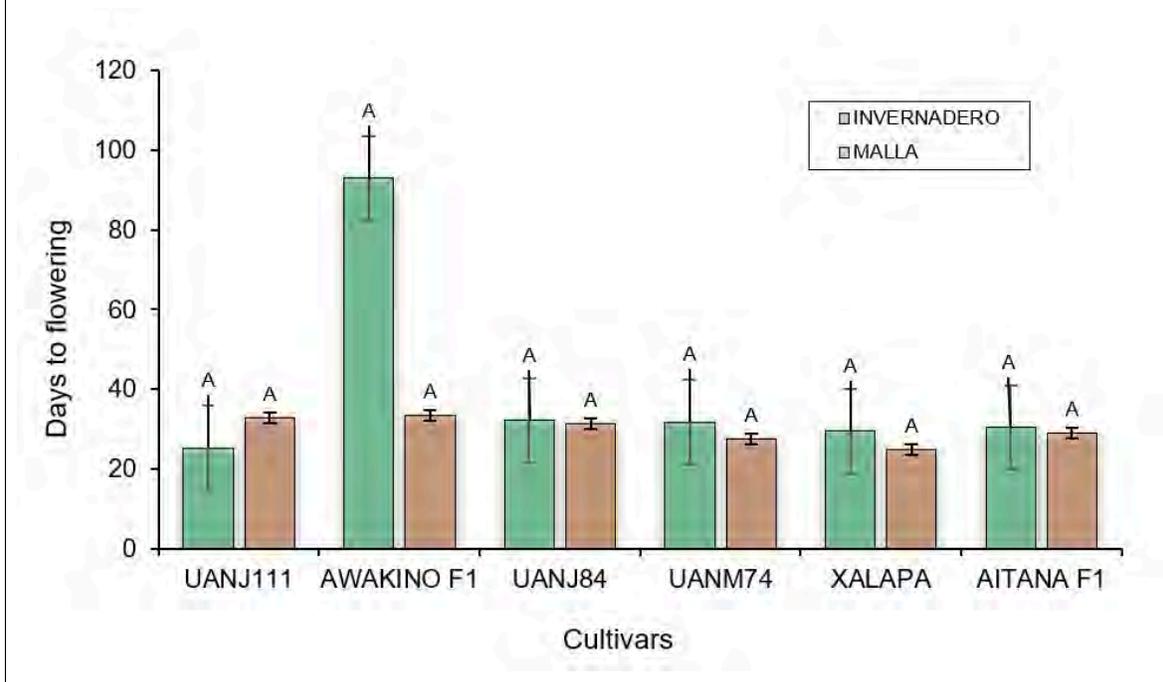
The treatments were the six materials established in the two environments, with three replications under each environment (greenhouse and shade net). The analysis of variance was performed in the SAS 2019 statistical package using the commands for a split-split plot design in randomized complete blocks. To determine the best treatment, Tukey's mean test ($p \leq 0.05$) was performed using the same software.

Results and discussion

Agronomic variables

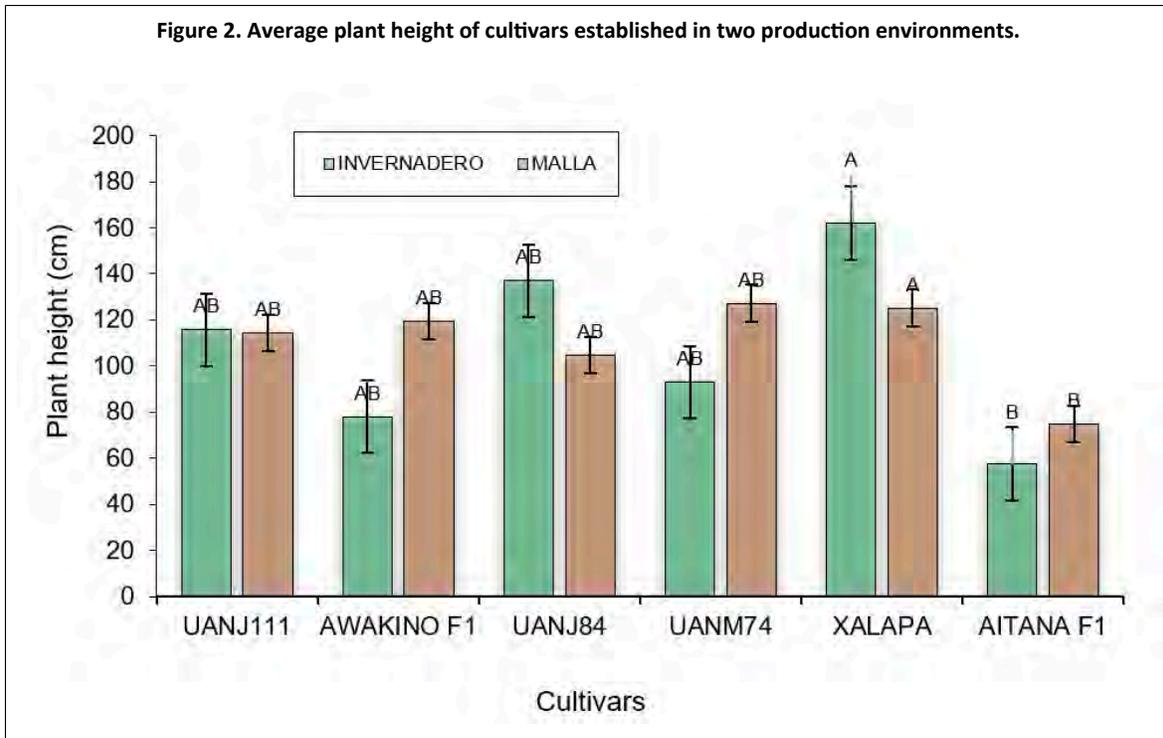
The analysis of variance showed significant differences ($p \leq 0.05$); for the DTF variable, the Awakino F1 cultivar was significantly later in the greenhouse (Figure 1), whereas the other cultivars had more uniform behavior in both environments.

Figure 1. Flowering of different cultivars of pepper (*Capsicum annuum* L.) established in a greenhouse and under a shade net.



The fact that flowering is early allows early production and represents an advantage in the market of at least 36 days; in contrast, the Awakino F1 material took longer to reach this phenological stage, which may be due to the reduction of light intensity, which can cause the delay of the appearance of flowers, as indicated by Blanco-Valdés (2019).

Regarding the PH variable, the analysis of variance ($p \leq 0.05$) showed that the Xalapa cultivar was significantly superior to the Aitana F1 cultivar in the greenhouse and under the shade net, but it was significantly equal to the Uanm74, Uanj84 and Uanj111 cultivars. Xalapa surpassed Aitana F1 by 182.77 in the greenhouse and by 67.6% under the shade net (Figure 2).



The results indicate that Uanj111 (jalapeño) is a very promising specimen for its production in protected environments. In this case, it was established in a shade net house, showing a height very similar to the height recorded in the greenhouse; this is very promising since at a greater height, more internodes can be generated and this translates into the generation of more floral growths, therefore, more fruits per plant.

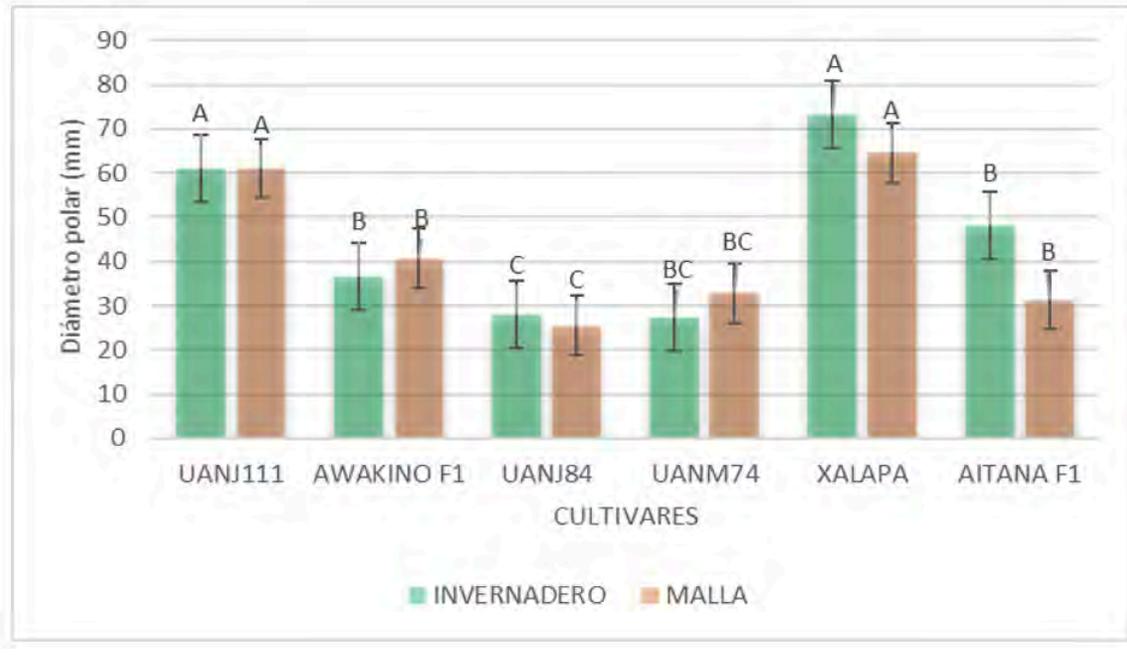
The use of these types of materials in protected environments aligns with what was reported by Hernández-Hernández *et al.* (2021), who mention that the use of genetically improved pepper cultivars in protected environments can be an alternative to the adverse effects of abiotic and biotic factors in open-field agriculture. The study by Escamirosa-Tinoco *et al.* (2021) points out that plastic covers for *Capsicum annuum* L. production significantly improve yields and fruit quality. This is consistent with the results obtained in the present study. This confirms the advantages of using improved *Capsicum* seeds in protected systems in order to face current challenges.

Fruit quality

The analysis of variance shows significant differences in the PD variable of the different established populations ($p \leq 0.05$); it is notable how Xalpa is outstanding in the aforementioned variable, which is very important for the production of this crop, since it shows that its quality is not reduced in the environments under study (Figure 3).

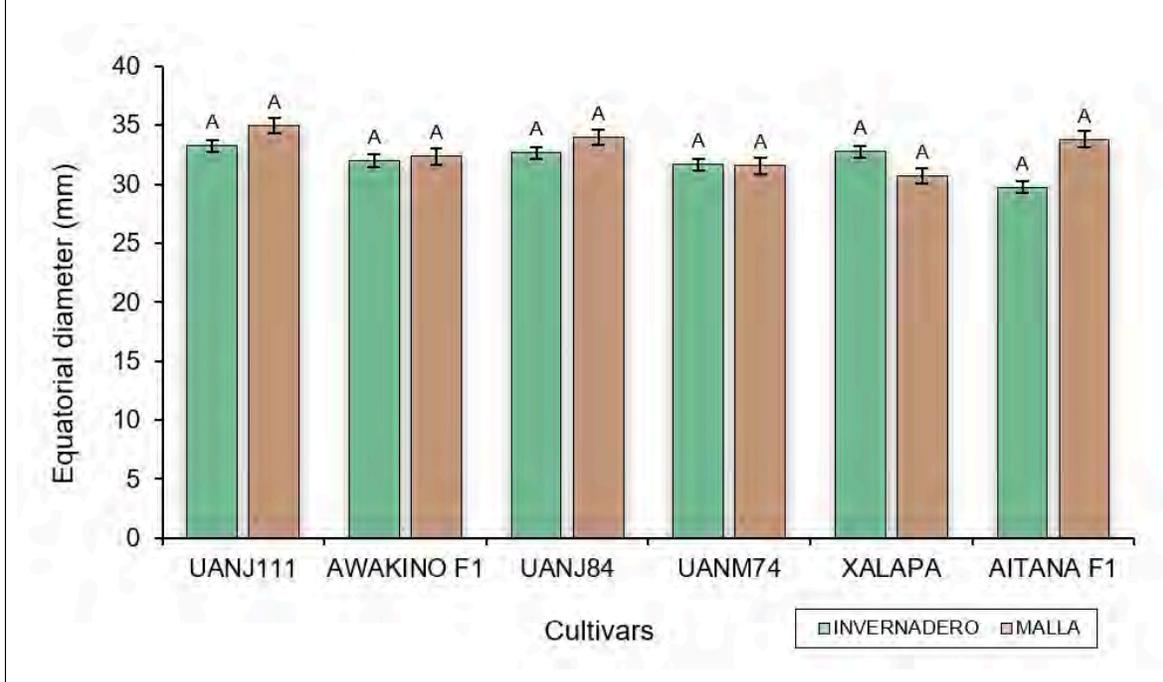


Figure 3. Variable “polar diameter” in its average values for the materials established in a greenhouse and under a shade net.



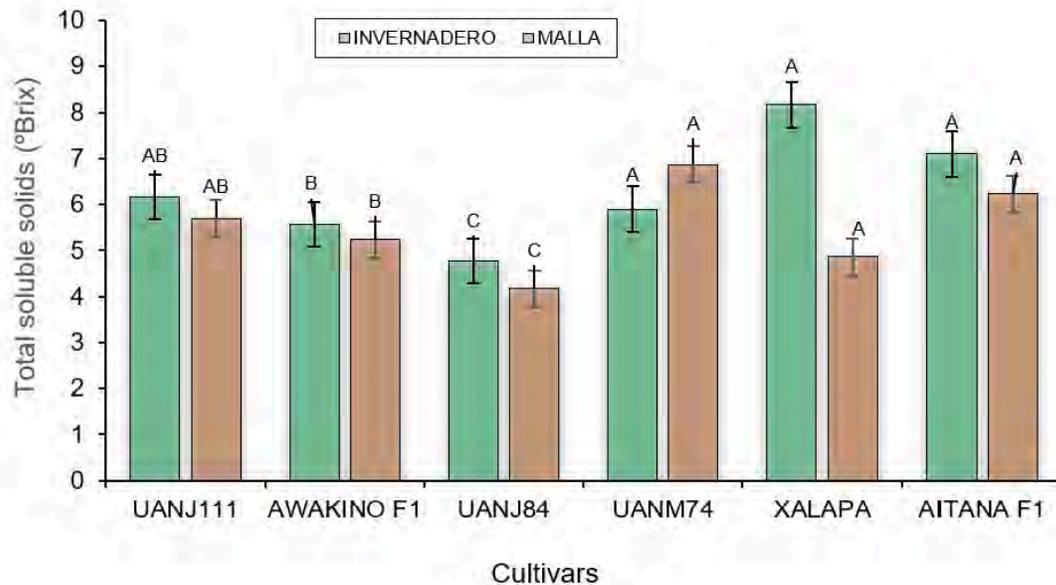
The analysis of variance performed for the ED variable ($p \leq 0.05$) shows that the EDs in the cultivars studied were significantly equal between the greenhouse and the shade net (Figure 4). The equatorial diameter of peppers could behave similarly due to the development and growth of the crop, as pointed out by Zhang *et al.* (2023); this is because of the homogeneous conditions within each environment and the crop’s adaptability to these environments.

Figure 4. Equatorial diameter of fruits obtained from cultivars established in a greenhouse and under a shade net.



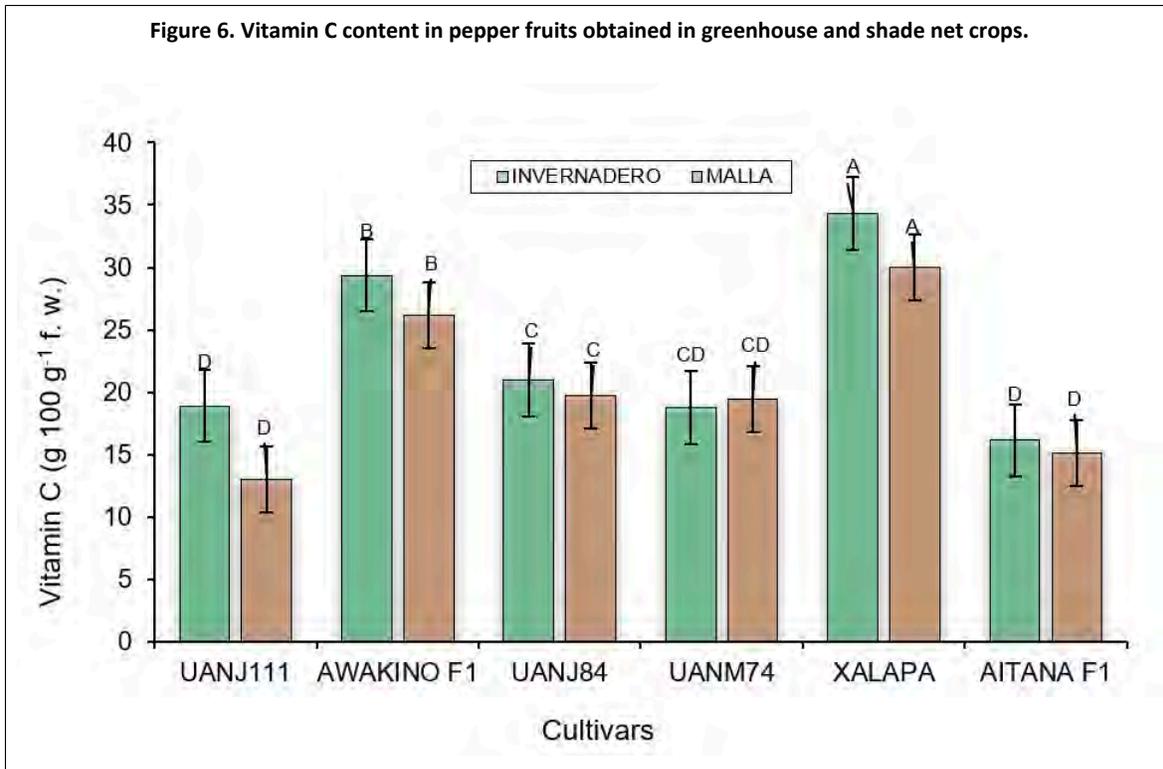
In the SST variable (Figure 5), it can be seen that Xalpa, grown in the greenhouse, presented fruits with 8.18 °Brix, 67.55% higher than the same cultivar grown under the shade net, which only presented 4.87 °Brix, indicating that using these types of cultivars in protected environments, such as greenhouses, shade nets, or macro tunnels, can induce changes in the nutraceutical properties of their fruits, which can be of great interest to the national and international market. It is important for agricultural sustainability and improvement in the quality of fruit and vegetable products (FAO, 2018).

Figure 5. Concentration of total soluble solids in the cultivars established in a greenhouse and under a shade net.



In the VC variable, significant differences were found between cultivars grown in the greenhouse; the Xalapa cultivar exhibited a value of 34.33, whereas under the shade net, this value was 30, 11.4 mg higher in the greenhouse than under the shade net (Figure 6); the same cultivar grown in a greenhouse environment lead to an improvement in the nutraceutical quality of this cultivar.





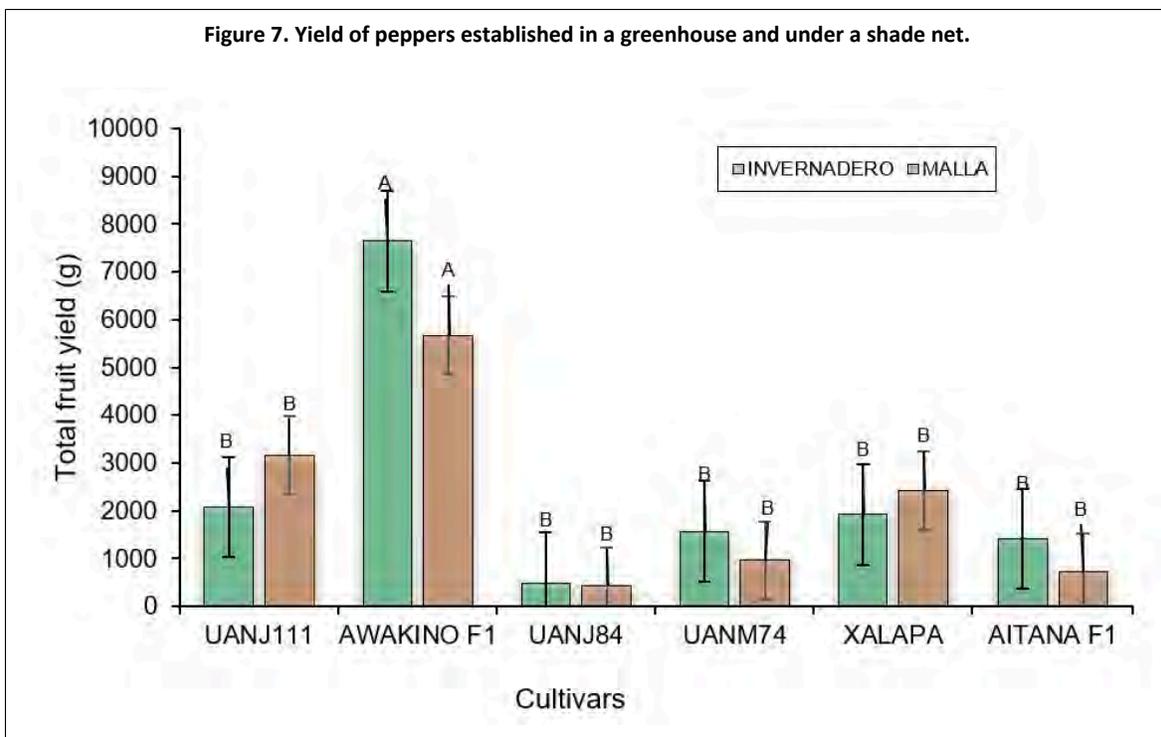
According to Vázquez *et al.* (2020), the presence of vitamin C improves the flavor and firmness of the fruit, which increases its quality and post-harvest life; the same authors report that, on average, the concentration of vitamin C in 0.1 kg is 96 mg, which tells us that the Xalapa cultivar exceeds this concentration by 35.7%; therefore, this reaffirms the use of protected systems for the production of *Capsicum*, which makes it more attractive to the market (Liu *et al.*, 2022).

Yield

The Awakino F1 cultivar was significantly higher in TFY (Figure 7) in both production environments, whereas the Uanj84 and Aitana F1 cultivars exhibited the lowest yields. The Awakino F1 cultivar adapted better to the greenhouse, but there were others that performed better under the shade net.

The Awakino F1 cultivar in the greenhouse exceeded the yield observed under the shade net by 34.66% (Figure 7), indicating that this cultivar should preferably be established in a greenhouse in order to achieve high yield, coinciding with Cedeño Guerra *et al.* (2020).





The use of greenhouses benefits the production of specialty peppers, in addition to increasing the quality of the fruits; on the other hand, Mendoza-Elos *et al.* (2020) point out that the exploration of improved genotypes is important for sustainable agriculture as it improves the quality of crops and helps to make the use of resources necessary for agriculture more efficient, in addition to making the use of resources, such as water and nutrients, in pepper production more efficient (Surnar *et al.*, 2025).

Conclusions

The cultivars under study responded differently to the two production environments, indicating the importance of evaluation to select the most appropriate production system.

The Xalapa, Awakino F1 and Uanj84 cultivars exhibited good yield and fruit quality in both production environments, which indicates that they can be taken to the productive sector for use.

The production environment can significantly influence the nutraceutical quality of the fruits of the pepper cultivars under study.

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