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# Evaluation of Agronomic Performance and Fruit Quality of Four Genotypes of Bell Pepper under Greenhouse Conditions

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Authors LSC, NCM, AFN and JSJGAR investigatión, conceptualization and wrote the protocol. Authors NCM, XRC, LSC, AFN, AAB, JSJGAR designed to study and methodology. Authors XRC, JIGL, NART managed the analyses of the study and validation. Authors LSC, NCM, AFN, XRC and NART managed the analyses of the study and supervision. Authors NCM, AFN, LSC, NART writing original draft preparation. Authors NCM, AFN and LSC writing review and editing. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** The objective of this experiment was to evaluate agronomic performance of four pepper genotypes under greenhouse conditions, and to determine the nutritional content of their fruits.
**Study Design:** Was with the completely randomized model with four treatments (genotypes P-01, P-02, P-03 and P-04) and four repetitions each. The comparison of means was by Tukey ≤.05.
**Place and Duration of Study:** Experimental greenhouse "The Bajío" Buenavista, Plant Breeding Department of the Universidad Autónoma Agraria Antonio Narro. between March 2021 to December 2021.
**Methodology:** Four genotypes of bell pepper were evaluated (P-01, P-02, P-03 and P-04), through the quantification and determination of morphological variables, yield, as well as the physicochemical and nutritional quality of the pepper fruits.
**Results:** Significant statistical differences were identified in the number of fruits per plant, highlighting P-03, P-04 with 13.81 and 13.53 fruits, in fruit length, the P-01 genotype exceeded the rest of the genotypes by more than 16.5 %. For physicochemical evaluations there were no significant differences, however, there was a 10 % increase in firmness and mesocarp thickness in the P-03 and P-04 genotypes. Regarding carotenoids, P-03 had 52 % more than the rest of the genotypes, the P-01 genotype stood out in antioxidant capacity with 6 and 15 % for ABTS and FRAP, while the P-02 genotype stood out in a 26 % for DDPH. The color of the fruits turned out to be yellow red, highlighting P-03 and P-02 in terms of luminosity.
**Conclusion:** Due to the length of the fruits, the genetic potential of the P-03 genotype could be exploited, while due to the number of fruits harvested per plant, the genotypes with the greatest potential are P-02 and P-04. The variables with differences between treatments can lead to the selection of genotypes of better commercial quality and greater fruit set.


*Keywords: Capsicum annuum; yield; election; productive potential; nutraceutical.*

## 1. INTRODUCTION

Currently, the food demand is more difficult to satisfy, hence the importance of working on the development of new varieties with high yield potential and fruit quality, in this sense taking advantage of genetic resources for the development and use of superior varieties. That allow to reduce production costs of protected agriculture systems is feasible, in Mexico in these production systems there is a significant percentage of varieties coming from foreign companies and generally at high costs [1]. Given this situation, it is necessary to produce varieties of chili pepper for cultivation in the greenhouse or open field, this as an alternative to improve their productivity in the producing regions, in this way, a more efficient use of inputs is promoted with the use of improved seeds, considering higher production, fruit quality and consequently a better cost-benefit ratio [2].

The bell pepper (*Capsicum annuum*) belongs to the nightshade family, it is a vegetable that is in great demand in India, the Middle East, the US, Europe and the countries of Southeast Asia, attracting the attention of farmers, consumers and traders in the international market, due to its rich nutritional profile and its increasing export potential [3]. In 2020, the area harvested worldwide was 2,069,990 hectares, of which a production of 36,136,996 tons was obtained, with an average yield of 17.45 tons per hectare [4]. Mexico reported in 2020 a bell pepper production of 2,103 planted hectares and a production of 226,374 tons under greenhouse condition at the national level [5]. In addition, the pepper ranks seventh among the main agrifood products exported in 2020, with a value of 1,527 million dollars, its main market being the country of Japan [6].

Peppers are a vegetable that presents a wide genetic variability, as well as a wide range of applications, in this context, studies on genetic diversity and characterization help to understand the existing variability and the conservation of genetic resources, since through the evaluation and characterization of populations, plant breeders can select superior genotypes and individuals that meet the needs of breeding programs in accordance with the objectives that are sought [7]. Currently, the agricultural sector implements diverse and varied products to improve the productive efficiency of crops, where the use of intensive agriculture such as greenhouses has been effective in promoting self-sufficiency of strategic crops [8], where there

is a more controlled production system [9], especially the climatic conditions that exert pressure on the yield of the new varieties and crops that are developed [10]. Within the large number of bioactive compounds that pepper contains, phenols, flavonoids, carotenoids and vitamin C are listed, which give it its great quality and interest in consumers and producers [11]. The maturity of the pepper fruits is a key factor to obtain the desirable quality of the same, being able to obtain a high contribution of vitamins and antioxidants to the consumer [12,13]. The existence of a range of fruit colors is due to genetic variation and the concentration of pigments, mainly carotenoids, vitamin C and antioxidant capacity, they are fruits rich in phytonutrients and considered as functional foods, in addition these bioactives can be variables used as selection characters and generation of new varieties [14]. It is important to mention that the phenols contained in the fruits are determined in the first instance by the variety, soil type, climate, stage of maturation, and growing conditions; as well as the post-harvest management and the nutritional status of the crop [15].

The improvement of peppers today is not only limited to obtaining higher yields and resistance to pests and/or diseases, but new varieties are now needed with fruits of desirable colour, flavour, aroma and nutritional quality, together with the resistance to pests and diseases, as well as tolerances to heat, cold, drought and salinity, these attributes represent important objectives for genetic improvement, where the development and use of new hybrid cultivars are key aspects of bell pepper production [3]. For this reason, the present study aims to evaluate the agronomic performance of four pepper genotypes under greenhouse conditions, and determine the nutraceutical quality of its fruits, under the hypothesis that at least one of the pepper genotypes will have a better agronomic performance under greenhouse conditions, and a higher concentration of nutraceutical compounds in the fruit.

## 2. MATERIALS AND METHODS

### 2.1 Location

The research was carried out in a medium technology greenhouse of the Plant Breeding Department of the Universidad Autónoma Agraria Antonio Narro (UAAAN), in Saltillo, Coahuila, located at 25° 21´ 24´´ LN and 101° 02´ 05´´ LO, at 1762 meters above sea level.

### 2.2 Seedling Production

The seeds of four genotypes of bell pepper identified as P-01, P-02, P-03 and P-04 belonging to the germplasm of the Seed Technology Training and Development Center of the Universidad Autónoma Agraria Antonio Narro. The seeds were sown on February 21, 2021 in 200-cavity polystyrene trays, the germination substrate was peat moss and perlite, in a 70:30 % ratio, respectively.

### 2.3 Field Establishment and Crop Management

The transplant was carried out 64 days after sowing the seeds and was carried out in coconut fiber in a pen, with a distance of 15 cm between plants, each plant led to a double stem. The supply of water and nutrients was by localized irrigation, with approximately 10 % drainage. The nutrient solution used for crop nutrition was modified Steiner type [16] as shown in Table 1 (50 % after transplant, 75 % at the beginning of flowering and 100 % at fruiting and filling). There were four genotypes representing four treatments, each with four repetitions, so each repetition consisted of six plants, one at each end as a border and four measurable and quantifiable useful plants. For the prevention and control of pests (whitefly, thrips, paratrioza), weekly applications were made of Spirotetramat at 15.3%, Spiromesifen at 23.1 %, Imidacloprid 17 % + betacylfutrin 12 % at a rate of 1 ml $L^{-1}$ and methomyl 90 %, at ratio of 1 g $L^{-1}$.

**Table 1. Nutrient Solution (SN) and the percentages used in the stages of bell pepper cultivation under greenhouse conditions**

| | $NO_3^-$ | $H_2PO_4^-$ | $SO_4^{2-}$ | $Cl^-$ | $HCO_3^-$ y $CO_3^{2-}$ | $NH_4^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ | $Na^+$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **% SN** | **Miliequivalentes $L^{-1}$** | | | | | | | | | |
| 100 | 12 | 2 | 7 | 3.26 | 1 | 2 | 7 | 4.5 | 9 | 3 |
| 75 | 9 | 1.5 | 5.25 | 3.26 | 1 | 1.5 | 5.25 | 3.4 | 6.75 | 3 |
| 50 | 6 | 1 | 3.5 | 3.26 | 1 | 1 | 3.7 | 2.5 | 4.5 | 3 |

## 2.4 Evaluatión of Agronomic Variables of the Crop

The stem diameter (SD) was quantified in mm, and was three centimeters from the base of the substrate, with a STEREN® digital vernier (HER-411), and plant height (PH) through the use of a PRETUL® (PRO-5MEB) flexometer graduated in centimeters, these two variables began to be evaluated two weeks after transplantation with intervals of fifteen days. Regarding the width (WL) and length of the leaf (LL), these were determined with a PRETUL® flexometer (PRO-5MEB) graduated in centimeters, and fully developed leaves were measured from the middle part of the plant, at 90 days after transplantation and the evaluation was unique. To quantify the distance between nodes (D/N) the same flexometer was used and it was 150 days after transplantation.

## 2.5 Fruit Yield Measurement and Their Components

The first harvest was carried out on August 11, the second on September 7, the third and fourth on September 17 and 24, the fifth, sixth and seventh harvests were on October 1, 9 and 19, respectively, 2021. The yield in grams harvested per plant (GPP), was estimated by weighing and adding the weight of all the fruits of each plant and in each of the harvests carried out, for them a digital scale GABATEC (GB-40) was used. At the time that the number of fruits per plant (NFP) was counted, in terms of the average fruit weight (AFW) in grams, this was calculated by dividing the total weight of fruits harvested from each plant by the total number of fruits per plant, the fruit width and length (WF and LF respectively) It was estimated by randomly taking four fruits for each experimental unit and it was carried out in the first two harvests, for which a digital vernier (STEREN® (HER-411) was used, which was used to measure the thickness of the mesocarp (TM ) data expressed in millimeters. In these same fruits, firmness was evaluated, and it was with a NEWTRY penetrometer with a measurement head (GY 03), with a pin diameter of 8 mm, °Brix was also determined with a SOONDA® refractometer (TD6010).

## 2.6 Physicochemical Evaluations of the Fruit

### 2.6.1 Fruit color test

As for the color characteristics, they were determined in the exocarp of 16 fruits taken at random from each experimental unit, taking the chromatic parameters (*L*, a*, b**), with a colorimeter Konica Minolta Sensing® (CR-400, Japón). The color parameters were determined with the CIELCH coordinates (*L*, C** and *h*), designed by the Commission Internationale De L'ecleirage (CIE) [17,18] L* defines the luminosity (0 black, 100 white), *C** (chrome; h saturation level) and h* (hue angle: 0° = red, 90° = yellow, 180° = green, 270° = blue). Color visualization was found with the online software ColorHexa [19] using the *L*, C*, h** values.

### 2.6.2 Fruit firmness

For the quantification of firmness in bell pepper fruits, the fruit was evaluated horizontally and by compression using a NEWTRY penetrometer with a measuring head (GY 03) with a pin diameter of 8 mm. In each one of the fruits the pericarp was perforated, with the necessary force for the penetration of the lace of 8 mm in diameter. The results were expressed in Kg $cm^{-2}$ of force.

### 2.6.3 Total soluble solids

To determine total soluble solids in the fruit (° brix in percentage), small pieces of fruit were cut with a knife, which were pressed to obtain a few drops of juice that were placed in the SOONDA® digital refractometer (TD6010, China).

## 2.7 Determination of Nutraceutical Quality

### 2.7.1 Collection and processing of plant material

The plant material used for fruit quality determinations corresponds to the first harvest, taking four fruits at random for each genotype repetition. The fruits were cut into small squares with a knife, 10 g of pepper were weighed on a Precisa precision balance (BJ 610C), each sample was placed in resealable polyethylene bags, this was for each of the corresponding determinations.

### 2.7.2 Phenol extract procedure

A sample of 10 g of chopped pepper was used, to which 50 mL of a 80 % methanol solution was added. The mixture was processed for one minute in an Osterizer® (6640-R22) blender, the mixture was transferred to 50 mL Falcon® tubes, from which 15 mL were taken and placed in conical centrifuge tubes. The sample was centrifuged at 5000 rpm for 5 min in a Labnet®

centrifuge (HERMLE z200A). Finally, the supernatant was recovered with a 3 mL Pasteur pipette in 10 mL amber bottles. These same extracts were used for the determination of antioxidant capacity.

### 2.7.3 Determination of total phenols

Phenols were determined in a spectrophotometer (UV-Visible Thermo Spectronic BioMate 3, Rochester, NY, USA). It began by preparing an 80 % methanol solution, where 0.0050 g of gallic acid (C7H6O5) was dissolved in a 25 mL volumetric flask, covered with aluminum foil and refrigerated. In a beaker, 3.5 g of sodium carbonate ($Na_2CO_3$) at 7 % was diluted in 50 mL of distilled water. In test tubes, 0.2 mL of each extract was added, mixing with 2.6 mL of distilled water and 0.2 mL of Folin-Ciocalteu reagent, to finally add 2 mL of 7 % Na2CO3 and the solution was stirred for 30 s. The reaction took place in the dark for 90 min, after which the absorbance of the samples at 750 nm was measured. The concentration of phenols was reported in equivalent milligrams of gallic acid per kilogram of the sample (mgGAE $kg^{-1}$), calculated from the calibration curve of gallic acid from 0 mg L-1 to 200 mg $_L^{-1}$.

### 2.7.4 Determination of antioxidant capacity

The antioxidant capacity of DPPH (2,2-diphenyl-1-picriolhydracil) was evaluated using a working solution of 0.0024 g of DDPH reagent in 80 % methanol, with an absorbance adjusted to 0.997 at 517 nm. The assay was performed by mixing 0.05 mL of the extract with 1.5 mL of the D PPH working solution, in graduated microtubes placed in a polypropylene cryogenic box, the reaction was left for 30 min in the dark and the absorbance was determined in a Thermo Spec-tronic BioMate 3 UV-Visible spectrophotometer.

The antioxidant capacity of ABTS (2,20azino-bis (3-ethylbenzothiazonyl-6-sulfonic acid)) was determined using a working solution obtained by mixing 0.0040 g of ABTS diluted in 1 mL of distilled water and 0.0070 g of potassium sulfate ($K_2S_2O_8$) diluted in 10 mL of distilled water; allowing it to react for 12 h in the dark. The absorbance of the working solution was adjusted to 0.996 at 734 nm by diluting with 80 % methanol. The ABTS assay was performed by mixing 0.05 mL of the extract with 1.5 mL of ABTS working solution. The reaction was left for 30 min in the dark, and the absorbance was measured in a Thermo Spectronic BioMate 3 UV-Visible spectrophotometer.

The antioxidant capacity of FRAP (ferric reducing antioxidant power) was determined using a working solution prepared by mixing 300 mM sodium acetate trihydrate C2H3NaO2.3H2O (pH 3.6), 10 mM TPTZ (2, 4, 6-tripyridyl-s-triazine, in 40 mM HCl), and 20 mM iron chloride hexahydrate FeCl3.6H2O in a 10:1:1 (V:V:V) ratio. The FRAP assay was prepared by mixing 0.05 mL of the extract with 1.5 mL of FRAP working solution; the reaction was left for 30 min in the dark at 37 °C, and the absorbance of the samples was taken at 593 nm in a Thermo Spectronic BioMate 3 UV-Visible spectrophotometer.

The antioxidant capacity for the DPPH, ABTS and FRAP tests will be reported in micromoles of Trolox equivalent (6-hydroxy-2, 5, 7, 8-tetramethylchroman-2-carboxylic acid) per kilogram of the sample (µmol TE $kg^{-1}$), according to the calibration curve with Trolox in concentrations from 0 to 500 mmol L-1. The evaluations of phenolic compounds and antioxidant capacity were quantified according to the method used by [18].

### 2.7.5 Procedure of carotenoids extracts

To obtain carotenoid extracts, 10 g of each of the pepper samples were taken and added to 60 mL of a hexane-acetone solution (200:400 v/v). The mixture was processed for one minute in an Osterizer® (6640-R22) blender, then the extract was placed in beakers, which were protected from light until the supernatant was recovered, which was finally deposited in 10-gallon amber bottles mL.

### 2.7.6 Determination of carotenoids

To determine carotenoids, the method of [20] was used with slight modifications. An extraction solvent (10:20 v/v) based on hexane and acetone was used. A polypropylene cryogenic box was used where 1 mL micrograduated tubes were placed, with micropipettes of varied volume, 0.1 mL of carotenoid extract and 0.9 mL of extraction solvent were added, leaving it to stand for a while until its absorbance at 475 nm was measured. a Thermo Spectronic BioMate 3 UV-Visible spectrophotometer. Results were reported as µg β-carotene g-1 fresh weight, using the β-carotene molar extinction coefficient of 2505$mM^{-1}$ $cm^{-1}$.

### 2.8 Experimental Design

The treatment design and the statistical model were completely randomized, with four treatments and four repetitions each, each repetition with four measurable and quantifiable useful plants. With the data obtained, an analysis of variance (ANOVA) was performed, and for the detection of statistical differences between genotypes, the Tukey mean comparison test ($p \leq 0.05$) was used using the statistical package InfoStat/L (InfoStat® version 2020).

## 3. RESULTS

### 3.1 Agronomic Performance

Regarding the agronomic evaluations of the crop, in the response variable of number of seeds per fruit, this was highly significant (Fig. 1), where the P-03 genotype stood out with a value of 309 seeds, surpassing the rest of the genotypes in percentage terms. genotypes by more than 50 %.

In the indicator variables of agronomic performance there was no significant statistical difference between genotypes, however, the P-02 genotype exceeded 10 and 21 % in stem diameter and leaf width, to the rest of the genotypes, while the P-03 genotype in the variables plant height and distance between nodes exceeded the rest of the genotypes by 5 % (Table 2).

### 3.2 Performance Components

As for some yield components, significant statistical differences were identified in the number of fruits per plant and fruit length, in the first P-03, P-04 and P-02 stood out with 13.81, 13.53 and 12.08 fruits harvested per plant respectively, while in the second the P-01 genotype exceeded the rest of the genotypes by more than 16.5 % (Fig. 2).

Although there was no significant statistical difference in the yield variable in grams harvested per plant (GGP), a percentage increase of 20 % was observed for the P-03 and P-02 genotypes compared to the P-01 genotype, the rest of the evaluated variables (AFW and WF) also showed a similar statistical behavior that indicates similarity in the behavior of the genotypes (Table 3).

### 3.3 Physicochemical Evaluations and Nutraceutical Quality

For the physicochemical evaluations, there were no significant differences in the response of the genotypes, however, there was a 10 % increase in firmness and mesocarp thickness in the P-03 and P-04 genotypes compared to P-02 and P-01 (Table 4).

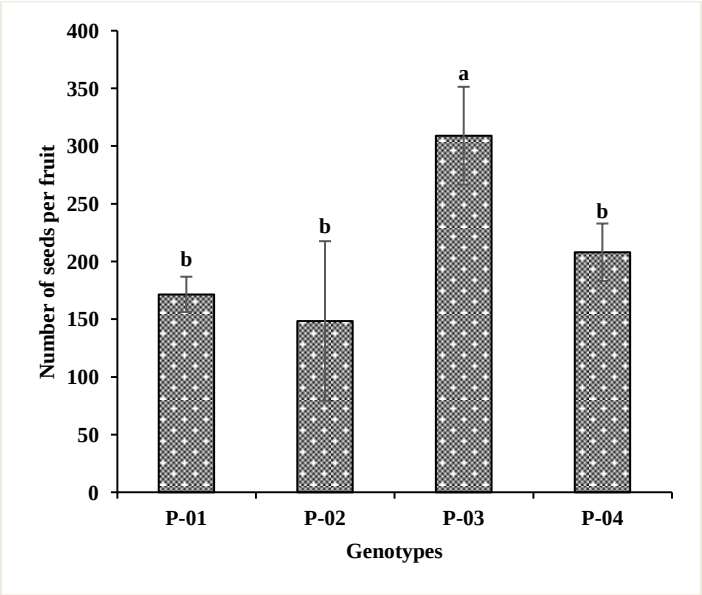



**Fig. 1. Comparison of means and standard deviation of the number of seeds per fruit evaluated in four genotypes of bell pepper under greenhouse**

**Table 2. ANOVA and mean test of agronomic performance indicators of four bell pepper genotypes evaluated under greenhouse**

| Genotypes | SD (mm) | PH (cm) | LL (cm) | WL (cm) | D/N (cm) |
|---|---|---|---|---|---|
| P-01 | 11.18 a* | 89.64 a | 18.12 a | 10.53 a | 38.84 a |
| P-02 | 12.39 a | 93.69 a | 18.43 a | 11.37 a | 42.10 a |
| P-03 | 11.58 a | 98.05 a | 17.86 a | 9.39 a | 44.56 a |
| P-04 | 11.29 a | 91.64 a | 18.98 a | 11.23 a | 33.08 a |
| significance | NS | NS | NS | NS | NS |
| CV (%) | 7.52 | 10.05 | 9.84 | 10.94 | 33.11 |
| MSD | 1.83 | 19.67 | 3.78 | 2.44 | 27.55 |

*NS= Not Significant, *= means with the same letter in the columns are statistically equal Tukey= (p ≤0.05), CV= Coefficient of Variation, MSD= Minimal Significant Difference, SD= Stem Diameter, PH= Plant Height, LL= Length of Leaf, WL= Width of Leaf, D/N= Distance between Nodes*

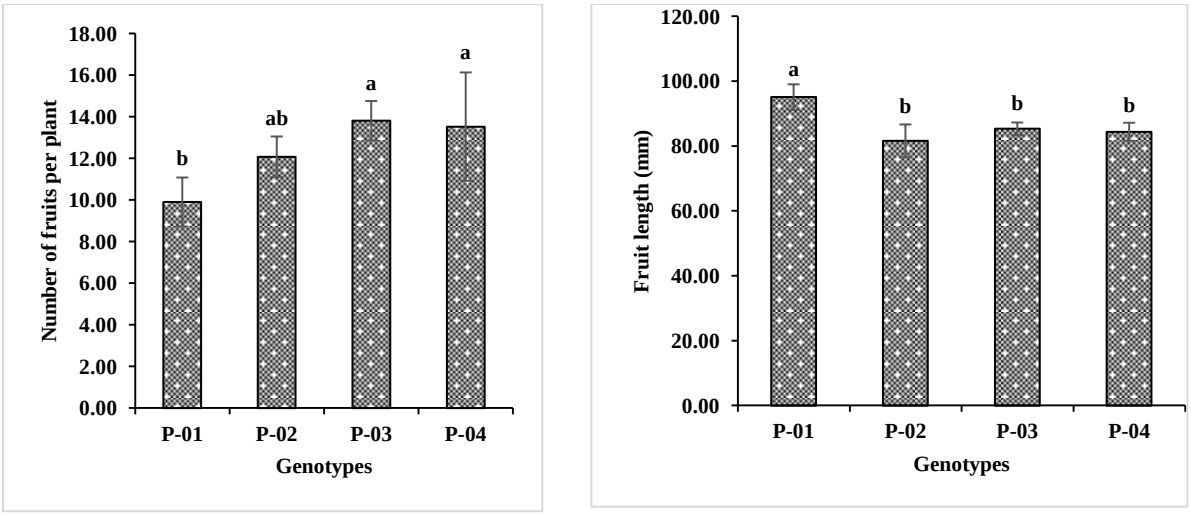



**Fig. 2. Comparison of means and standard deviation of the number of fruits per plant (A) and fruit length (B) of four bell pepper genotypes evaluated under greenhouse conditions**

**Table 3. ANOVA and test of yield means and yield components in four bell pepper genotypes evaluated under greenhouse**

| Genotypes | GPP (g) | AFW (g) | WF (mm) |
|---|---|---|---|
| P-01 | 1818.58 a | 193.42 a | 83.13 a |
| P-02 | 2204.88 a | 184.68 a | 86.17 a |
| P-03 | 2232.92 a | 167.38 a | 85.03 a |
| P-04 | 1988.50 a | 148.76 a | 81.20 a |
| Significance | NS | NS | NS |
| CV (%) | 16.02 | 14.24 | 4.27 |
| MSD | 693.25 | 51.88 | 7.51 |

*NS= Not Significant, CV= Coefficient of Variation, MSD= Minimal Significant Difference, means with common letter are not significantly different Tukey= (p ≤0.05), GPP= Grams Per Plant, AFW= Average Fruit Weight, and WF= Width of Fruit*

Regarding the evaluations of the nutraceutical quality of the fruit, no significant statistical differences were observed either, however, in the content of phenols, the P-04 genotype obtained 20 % more than the rest of the genotypes, while P-03 obtained 36 % more carotenoids, while in antioxidant capacity with the DDPH method, the P-02 genotype stood out by more than 15 % than the rest of the genotypes (Table 5).

Regarding the determination of fruit color, statistically significant differences in luminosity

(L*) were observed, indicating that the analyzed samples revealed a tendency more towards white than towards black. The parameter L* was lower in P-01 with 30.47, while the highest value was presented in P-02 with 32.02, followed by P-04 and P-03, as well as the highest value of C* with 15.45, which indicates a higher color saturation, while the lowest C* value was 13.08 in the P-01 genotype. The color of the fruits turned out to be yellow red according to the color classification (Table 6).

## 4. DISCUSSION

### 4.1 Agronomic Performance

In order to have a quantity and quality production, an adequate fertilization is necessary, which translates into an optimal agronomic performance of the crops [16]. The statistically significant result observed in some traits of agronomic performance can be attributed to the fact that the number of seeds and the size of the fruits depend on pollination, that is dependent on the requirement of temperatures and relative humidity of the environment and as well as the vegetative phase in which they are found [17,18]. The temperatures and their accumulation in degree days of development condition the flowering and fruiting processes, which induce the formation of seeds and these in turn determine the shape and size of the fruits [19]. Moreover, the development for the growth and development of the fruits must have adequate solar radiation [20], in such a way that the leaf surface produces enough photosynthetic assimilates that contribute to their growth. Since the temperatures induce floral differentiation and the formation of large numbers of flowers, which generally occurs with optimal daytime temperatures ranging from 24 to 26°C and night temperatures from 18 to 20°C, with temperatures below 18°C, pollen viability decreases, producing smaller fruits with few seeds [18].

**Table 4. ANOVA and test of means of total soluble solids, fruit firmness and mesocarp thickness of four bell pepper genotypes evaluated under greenhouse**

| Genotype | Total soluble solids (°Brix) | Fruit firmness (Kg cm$^{-2}$) | Mesocarp thickness (mm) |
|---|---|---|---|
| P-01 | 6.62 a* | 3.97 a | 7.00 a |
| P-02 | 6.55 a | 3.57 a | 6.63 a |
| P-03 | 6.41 a | 4.05 a | 7.36 a |
| P-04 | 6.42 a | 4.09 a | 7.33 a |
| Significance | NS | NS | NS |
| CV (%) | 7.02 | 6.44 | 7.25 |
| MSD | 0.96 | 0.53 | 1.07 |

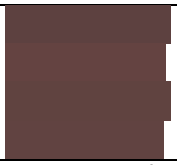
*NS= Not Significant, *= means with the same letter in the columns are statistically equal Tukey= (p ≤0.05), CV= coefficient of variation, MSD= Minimal Significant Difference*

**Table 5. ANOVA and mean test of phenols, carotenoids and antioxidant capacity (ABTS, DDPH and FRAP) of four bell pepper genotypes evaluated under greenhouse conditions**

| Genotype | Phenols (mgGAE kg-$^{1}$) | Carotenoids (mg/100 g) | Antioxidant Capacity (µmolTE/kg-$^{1}$) | | |
|---|---|---|---|---|---|
| | | | ABTS | DDPH | FRAP |
| P-01 | 507.04 a* | 20.22 a | 2377.47 a | 2167.57 a | 6736.20 a |
| P-02 | 498.50 a | 22.54 a | 2224.65 a | 2679.45 a | 6075.47 a |
| P-03 | 496.42 a | 30.79 a | 2354.05 a | 2121.77 a | 5852.90 a |
| P-04 | 607.64 a | 22.50 a | 2340.84 a | 2336.61 a | 6657.51 a |
| Significance | NS | NS | NS | NS | NS |
| CV (%) | 21.15 | 28.79 | 11.73 | 28.88 | 10.04 |
| MSD | 234.12 | 14.51 | 572.44 | 1410.64 | 1333.71, |

*NS= Not Significant, *= means with the same letter in the columns are statistically equal Tukey= (p ≤0.05), CV= coefficient of variation, DMS= Minimal Significant Difference, phenols, carotenoids and antioxidant capacity (ABTS, DDPH and FRAP)*

**Table 6. Chromatic parameters of fruits of four bell pepper genotypes evaluated under greenhouse**

| Genotypes | Colocolor parameters | | | |
|---|---|---|---|---|
| | ***L**** | ***C**** | ***h**** | **Color view** |
| **P-01** | 30.47 ± 0.58 b | 13.08 ± 3.27 a | 24.26 ± 6.17 a |  |
| **P-02** | 32.02 ± 1.16 a | 15.45 ± 2.35 a | 27.05 ± 4.31 a | |
| **P-03** | 31.47 ± 0.27 ab | 13.74 ± 1.87 a | 28.86 ± 6.68 a | |
| **P-04** | 31.57 ± 0.40 ab | 14.02 ± 1.78 a | 25.98 ± 4.17 a | |

*L*: Luminosity; C*: Color saturation; h: pitch angle. Values are the average of four replicates. Means (n=4) ± standard deviation. Different letters within each column mean that the treatments were statistically different (Tukey, p≤0.05)*

The agronomic performance of a crop depends on the variety that is planted, however, it also depends on the environmental conditions during its growth and development, the management of the crop, as well as the availability of nutrients and moisture in the culture medium [21]. To the above is added an adequate supply of water, in order to achieve performance goals, of course without neglecting the ionic balance of the nutrients that accompany it [22]. The average number of seeds per fruit obtained in this research work was similar to those found in pepper hybrids, with 174 seeds per fruit [23], but higher than that obtained from the 60 seeds per fruit reported by the FAO [24].

It is important to point out that the seeds obtained were from segregating populations in F3, showing similar results to commercial pepper hybrids. Regarding the growth of the pepper plant, Hernández-Montiel et al. [25] obtained an average plant height of 92.38 cm, while for the stem diameter it reported 10.04 cm, lower values compared to the data of the present work.

## 4.2 Performance Components

Improving the agronomic performance of any crop is largely based on the existence of existing genetic variability, and the magnitude of beneficial genetic variability available [26]. The agronomic response of the genotypes in fruit length are similar to the 80.5 to 93.5 mm obtained by Mata and Ramos [27], however, in terms of number of fruits per plant, they determined inferior results compared to the fruits obtained in this research. Of equal importance, in another study similar lengths were reported in square-shaped pepper genotypes up to 95 mm [28]. However, Castillejo et al. [29] obtained fruits with width and length of 87.2 and 87.6 mm, respectively, and with an average weight greater than 204.7 g.

Taking these data into account, it is important to mention that the length of the fruit is one of the characteristics that most influences and contributes to yield [30]. What coincides in the studied genotypes P-02 and P-03, which obtained a percentage higher yield, while the fruit length of P-02 was slightly lower, and P-03 had an intermediate size. On the other hand, in the width of the fruit, these two genotypes (P-02 and P-03) were the ones that showed a favorable result. It is important to highlight that for the selection of genotypes to be more effective, it is important to take into account the width of the fruit, since Achal et al. [31,32] argue that the characters: plant height, fruit length, fruit width and number of fruits per plant turn out to be of high heritable capacity, so the selection of new materials should be made based on these characters.

## 4.3 Physicochemical Evaluations and Nutraceutical Quality

The perfect combination that adjusts between the phenological stages of the pepper (flowering, fruit production and ripening stages) is based on an efficient irrigation pattern, radiation and nutrients, which influences the physiology, fruit quality, content total soluble solids and hardness, with higher yield [33,34]. Peppers have a wide sensory and nutritional variability, among the sensory characteristics that stand out are the thickness of the wall and the total soluble solids [35]. In this research, there was no significance in the physicochemical evaluations, however, the P-03 and P-04 genotypes stand out percentage-wise in mesocarp firmness and thickness, which are considered in the different quality attributes (firmness, thickness of wall and content of soluble solids) for its multiple uses, in addition, these characters determine its commercial importance that is directly correlated with its freshness, texture and

quality attributes as important aspects for consumers [36].

Fruit firmness is another quality parameter related to storage time and shelf life, for this reason high values are desirable for products that travel long distances to reach consumers. The firmness values in fruits of this research are lower than the 5.3 and 5.4 kgf reported by Urrestarazu et al. [37] in pepper hybrids, but higher than 0.35 to 0.39 kgf reported by Guerra et al. [38] and 2.17 kg $cm^{-2}$ indicated by Uresti et al. [39]. Regarding the content of total soluble solids, values between 6.1 to 6.4 °Brix have been reported [37], averages of 5.11 °Brix, coinciding with the genotypes P-03 and P-04 of this research, but lower than 8.5 a 9.1°Brix [38]. The thickness of the wall of their fruits were lower with 5.31 to 6.03 mm, since reported that the firmness of the fruit is associated with the general conditions of the crop, and the thickness of the wall, responds to increases in solar radiation intercepted by the crop, which improves its quality by increasing the size and weight of the fruits [37]. In addition, there is a direct relationship between the carbohydrates contained in the fruit juice with the content of dissolved minerals [40].

With reference to the color of the fruit and its chromatic characteristics, this is a qualitative aspect of the fruits, the pepper is a widely consumed product, especially due to its colorful and striking appearance, sweet taste and healthy appeal [41,42]. The color of the fruit and its brilliance turns out to be a quality character, as well as its shape and size, these depend on the specific physiological processes that occur during maturity and his genetics [43]. Today, bell pepper consumers tend to demand better quality consumer products, therefore, the external appearance of the fruit and its uniformity are important criteria used by seed companies for the selection of their new varieties. In recent years, quality factors are focused on internal quality, that is, using these parameters in the selection of genotypes [35,44,45]. In the present research these parameters were also of great importance, which showed statistical significance, in luminosity (*L**) the P-02 genotype stood out with a value of 32.02, although the value is lower than that of pepper cultivars reported by López et al. [46] with a datum of 39.1 luminosity, Similar trends have been reported in red California-type peppers evaluated by Martín [44], where the (*L**) was slightly higher with 35.6, while the chromaticity (*C**) and hue angle (*h**) values reported by this researcher, exceeded those obtained in this investigation.

Bell peppers happen to be popular vegetables due to the combination of color, flavor, and nutritional content; however, different colors of bell pepper have different nutritional values such as antioxidant capacity, phenols, and carotenoid content [47-49]. With reference to this, Cortés-Estrada et al. [50] reported higher values in red peppers, with a fruit phenol content of 10250 mg GAE $kg^{-1}$. It should be noted that the content of phenols in red peppers is higher than the green ones, because these increase as the degree of maturation increases; that is, phenols depend on both the variety and the stage of maturity [12]. Regarding the content of carotenes, the results were lower than 850 mg GAE $kg^{-1}$ [51]. Finally, the antioxidant capacity values were considerably high, both by the DDPH and ABTS methodology, with 4.85 molTE/g and 65.56 molTE/g, respectively. It should be added that the antioxidant capacity values vary depending on the test applied, this variation reveals the different sensitivity of each test to gallic acid used as reference [51]. In relation to this, Cares et al. [14] observed that the antioxidant capacity was 1281 µmol Trolox/100 $g^{-1}$, where the determination method was different from those used in this investigation, so that the values obtained differ.

In other investigations, red bloky-type hybrids [18], carotenoid contents of between 2.7 to 3.08 µg/100 $g^{-1}$ were obtained, values well below those discovered in the genotypes that were evaluated in this investigation. Mohammed et al. [52] obtained fruits with a low content of carotenoids, ranging from 0.84 to 0.86 mg/100 $g^{-1}$ compared to the fruits of this research, which found between 20.22 to 30.79 mg/100 $g^{-1}$ of carotenoids. The content of phenols is part of a signal system, activated by different stress conditions to which the plant is exposed Guzman [53], also reported fruits with phenol content between 88.5 to 109.8 mgGAE/100$g^{-1}$. Foods that have antioxidant content are positive for cardiometabolic health and cognitive functioning in humans. Red peppers evaluated by Cortés-Estrada et al. [54] had an antioxidant capacity of 701.1 for ABTS and 52.2 for DDPH expressed in µmol Trolox/50 mL, results much lower than those described in this investigation, since for ABTS the values ranged between 2224.65 to 2377.47 and for DDPH between 2121.77 to 2679.45 in µmolTE/$kg^{-1}$.

## 5. CONCLUSION

The agronomic performance of the P-03 genotype in fruit length indicates high genetic potential for this character. While, in number of fruits harvested per plant, the genotypes with the greatest potential are P-03 and P-04, genetic characteristics that could be of interest and usable for breeding programs, through the selection of outstanding individuals within the genotypes.

In fruit quality parameters, it was observed that the total soluble solids are closely related to the content of phenols and carotenoids, compounds that increase with the maturation of the fruit, and in turn determine the typical reddish coloration of the fruits of the genotypes that were evaluated. Likewise, the fruits with a thicker mesocarp have a higher degree of firmness, a characteristic that contributes to the longevity of the fruits on the shelves, being favorable at the time of their commercialization.

The agronomic performance of the genotypes was slightly variable under greenhouse conditions, variability that is attributed to the genetics of the genotypes, which could be used for the generation of genetic variability or which would eventually allow the generation of lines for the generation of new hybrids or varieties of bell pepper for northeastern Mexico.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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