ARTICLE / INVESTIGACIÓN

# Agro-productive response of pepper hybrids in a tropical sheltered production system

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**Abstract:** The present work aimed to evaluate the agro-productive response of bell pepper 'Robur F1' and 'Clair F1' hybrids. The experiment was conducted in a tropical sheltered production system at the "Valle del Yabú" Agricultural Enterprise. The experimental design was a randomized complete block with four replicates. The height and diameter of the main stem, length of internodes, and number of days to flowering were evaluated. Additionally, the number of fruits per plant, average fruit weight and yield, and fruit quality attributes (thickness of the pericarp, length, top width, color, shape, and number of lobes) were recorded. Results showed that 'Robur F1' reached a higher height (33.9 cm), the diameter of the main stem (12.9 mm) and the length of the internodes (9.84 cm). 'Clair F1' showed the highest number of fruits per plant (12), average fruit weight (273.60 g), and yield (3.87 kg/m$^2$). A higher pericarp thickness and fruit width were observed in 'Clair F1', while the fruit was longer in 'Robur F1 (13 cm). Both hybrids had green bell peppers and fruits. With the knowledge of agro-productive characteristics of both pepper hybrids, Cuba may select the most remarkable genotype under a tropical sheltered production system.

**Key words:** Agricultural yield, Capsicum annuum, fruit quality, morphological traits.

## Introduction

Agro-plasticulture and all the associated technologies mark a line of agricultural development indispensable to increase the yields in some crops, improving environmental conditions to facilitate the growth and development of horticultural species[1].

The greenhouses in cold and temperate countries and the protected cultivation in the tropical region are modalities of agriculture under plastic that allow convert zones with some agro-productive limitation, extend the harvest calendars of many horticultural species and increase productive potential[2].

Vegetables worldwide are essential foods for humans because they contain vital nutrients. The cultivation of vegetables is increasingly attracting consumers. One of the crops prioritized in these systems is the pepper (*Capsicum annuum* L.), which occupies a prominent place in horticultural production because of its preference in the human population due to its exquisite taste and high nutritional value[4].

The pepper, belonging to the family Solanaceae, is native to Central and South America. According to FAOSTAT[5], the harvested area of pepper in the world in 2020 was 2 069 990 ha, with a production of 36.1 million tonnes. In the world condiment trade, it occupies the second place. The sweet pepper is consumed in fresh condition, and some cultivars with a high spiciness, in addition to being used as food, are used as a medicine for their remarkable contents of vitamins A and C[6].

In Cuba, in 2020, the pepper occupied a cultivated area of 7,621 ha and a production of 59,285 tonnes5. The cultivars commonly used are Tropical CW-3, Spanish, Maor and SC 81[7], and Milor F1 and Lical resistant cultivars[8].

One of the main problems that limit pepper production in Cuba is the introduction of foreign hybrids without previous knowledge of their agro-productive characteristics under a tropical sheltered production system. The present work aimed to evaluate the agro-productive response of two pepper hybrids under a sheltered production system.

## Materials and methods

This study was carried out in a tropical sheltered production system, model Tropical A-12 designed by the Cuban-Spanish company CARISOMBRA with 540 m$^2$ (12 m wide and 45 m long), a height at the top of 4 m and an umbrella effect (typology 2) on Inceptisol soil belonging to protected cultivation module in the Agricultural Enterprise "Valle del Yabú", Santa Clara, Villa Clara, Cuba during October 2019 to March 2020.

Seed of pepper hybrids Clair F1 and Robur F1 (Enza Zanden, Netherlands) were sowed on August 25, 2019, and placed in trays of polystyrene with 247 cells (2.9 x 2.9 x 6.5 cm, volume of 32.5 cm$^3$. The tray substrate used was 100 %

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Blonde peat, treated with a *Trichoderma harzianun* bioproduct (strain A-34) at a rate of 300 ml per 10 kg of substrate. Before sowing, the seed was treated with systemic insecticide imidacloprid (Gaucho FS 60) at 70 g per kg of seed.

Seedlings were transplanted on October 13rd. The planting distance was 1.20 m x 0.40 m in a double row on the bed under a randomized complete block design with treatments replicated four times. A drip irrigation system was used with a black flexible PVC irrigation pipe of 16 mm in diameter. Drippers separated at 0.39 cm and a flow of 2.0 L $h^{-1}$.

The agronomic management of the crop (vertical handling, offspring, defoliation, fructification pruning, beheading and pest management) was carried out as established in the Manual for producing protected vegetables[9].

### Evaluation of morphological characteristics

Evaluations of morphological characteristics were carried out on 30 plants per treatment. Height and diameter of the main stem (mm) were recorded at 15, 30 and 45 days after the transplant (DAT). Height was measured with a nonelastic measuring tape, and diameter was recorded in the middle part of plants with a Vernier caliper. The internode length (on primary side shoots) was recorded 45 days after the transplant (DAT). The number of days to flowering (days) was determined when 50 % of the flowers were open.

### Agricultural performance and yield components

Harvests were made when the fruits presented the state of beginning of maturity (physiological maturity). In total, 28 harvests were carried out throughout the productive cycle, in which the agricultural yield and its main components were determined. They were evaluated in 30 plants in each hybrid.

- Number of fruits per plant was registered at 85 days after the transplant (DAT) when the first harvest was done. The average weight of the fruit (g) was recorded using a digital analytical balance (Brand Kern PRS 320-3, Germany) in 60 fruits taken at random.
- Determination of agricultural yield (kg/$m^2$) was done by randomly harvesting all fruits of all plants in 1 $m^2$ at five different points. Fruits were weighted on a digital analytical balance.

### Fruit quality

At harvest, the following qualitative and quantitative fruit quality attributes were evaluated in 20 randomly chosen fruit. Pericarp thickness, fruit top width (mm) and length (mm) were determined with a Vernier caliper. Fruit skin color was determined visually at physiological maturity. Fruit shape and the number of fruit lobes were evaluated[10].

### Statistical analysis

Statistical analysis and significance were calculated using a one-way ANOVA and the post-hoc t-Student test. A P-value < 0.05 was considered statistically significant. Statistical processing was performed using the Statgraphics Centurion software package (version 16.1.11, StatPoint Technologies Inc., Warrenton, Virginia, USA).

## Results and discussion

### Height of the main stem

Robur F1' at 15, 30 and 45 DAT had a longer main stem than to hybrid 'Clair F1' (Figure 1).

In pepper, height is measured to the first bifurcation immediately after the first harvest. According to the pepper descriptor, five categories of plant height may exist (category 1 less than 25 cm, category 2 from 25 to 45 cm, category 3 from 46 to 65 cm, category 4 from 66 to 85 cm and category 5 more than 85 cm. Both studied hybrids belonged to category 2.

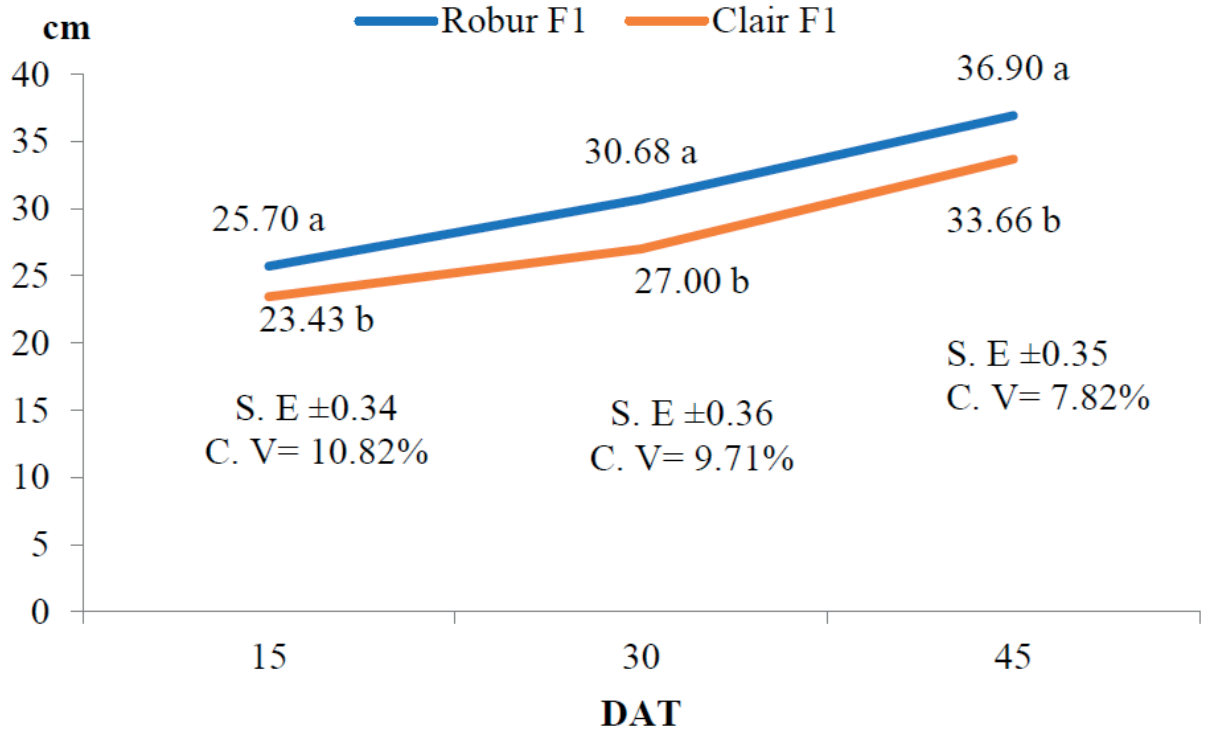



**Figure 1.** Plant height of the main stem of two bell pepper hybrids during the crop cycle, (a, b) Treatments with the same letter are not significantly different by t-Student test (p≤0.05) (DAT)= Days After Transplant, S.E = Standard error, C.V = Coefficient of variation.

Plant height is associated with competitive vigor, plant fecundity, aboveground biomass, rooting depth, lateral spread and leaf size, and plant density[11]. In the pepper breeding program, evaluation of the height of the main stem was associated with hybrid vigor[12] and may manifest heterosis for earliness, fruit yield, and yield attributing characters in sweet pepper[13].

Harrison *et al.*[14] considered the height of the main stem of great importance since it is sought that the fruits may be placed a long distance from the ground so that it can reduce the splash of water. The values obtained in the Clair F1 and Robur F1 hybrids were superior to those obtained by Herison[14].

**Diameter of the main stem**

The hybrid Robur F1 at 15, 30 and 45 DAT had larger diameter of the main stem respect to hybrid Clair F1 (Figure 2).

The diameter in pepper genotypes is measured in the middle part of the first bifurcation immediately after the first harvest. Stem diameter have been successfully used to estimate genetic diversity in segregating the F2 Population of Ornamental Pepper. Some studies of ornamental pepper indicated recessive alleles are responsible for the increase in stem diameter[15].

The stem diameter of pepper is one of the morphological characteristics commonly evaluated to improve response to drought[16], effects of mycorrhizal fungi inoculation on yield[17], selecting *Bacillus* species with growth-promoting properties[18] and improving mineral uptake[19].

**The length of the internode**

The highest internode length was recorded in the Robur F1 hybrid with 9.84 cm, while Clair F1 only reached 7.68 cm (Figure 3).

Pepper shoots can be varied into long shoots or short shoots based on the distance between buds. Gibberelins biosynthesis in close related to the length of internode in plants[20]. Otherwise regulation of Cytokinins pathway signaling reduced internode lengths[21]. The size of internode and aerial root may increase with the application of NPK fertilizer on the early growth of Black Pepper[22].

**Number of days to flowering**

Statistically significant differences were found between both hybrids. Clair F1 reached 50% of the bloom at 22 days after the transplant, while Robur F1 at 20 days (Figure 4).

The number of days to flowering was counted from transplanting until 50 % of plants have at least one open flower. Similarly, Usman[23] indicated the usefulness of the variable days to flowering because it showed a negative correlation with yield in chili peppers at the genetic level. In our study, correlative analysis was done.

**Number of fruits per plant, the average weight of the fruit and agricultural yield**

Clair F1 had more fruit per plant than the Robur F1 hybrid because Clair F1 produced more flowers per plant and less flower abortion. The higher average fruit weight was recorded on the Clair F1 hybrid (273.60 g), and found

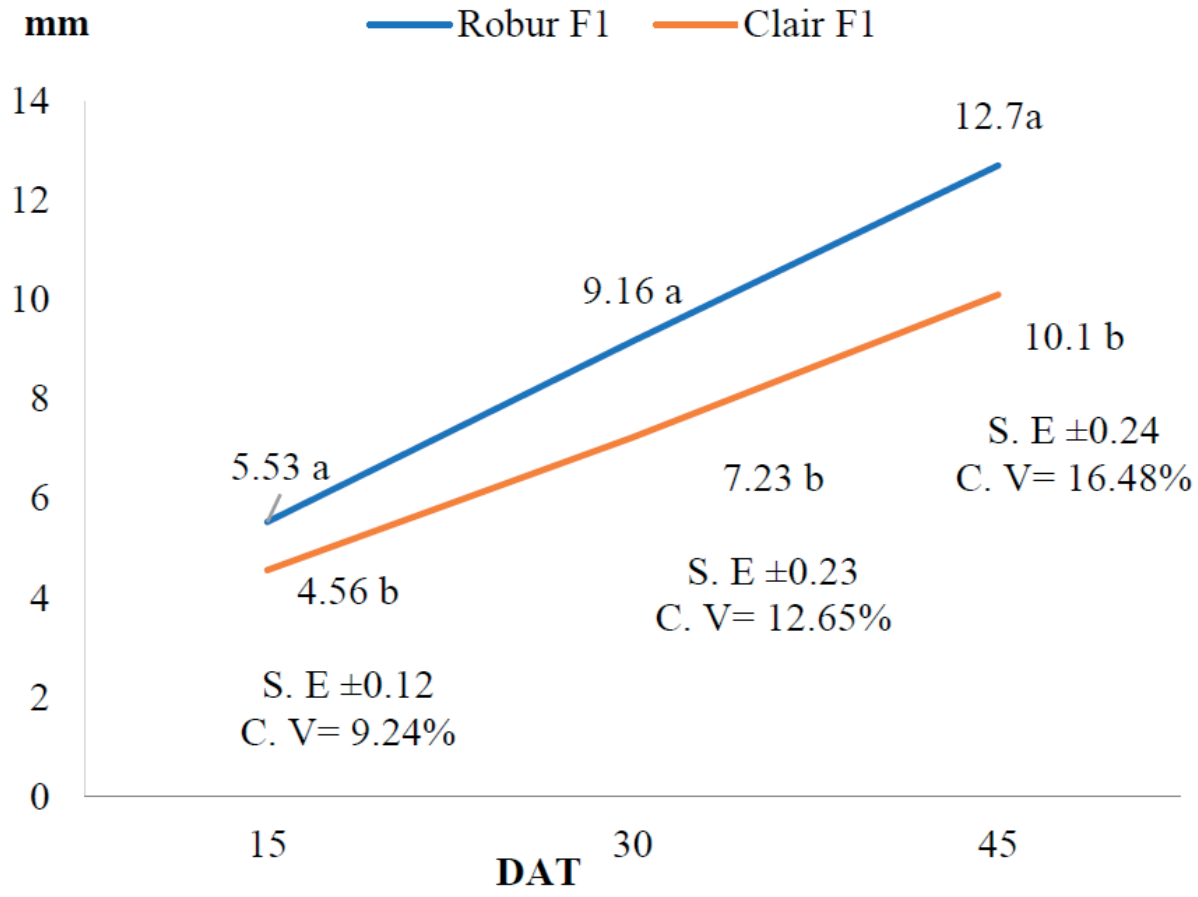



**Figure 2.** Stem diameter of two bell pepper hybrids during the crop cycle.
(a, b) Treatments with the same letter are not significantly different by t- Student test (p≤0.05)
(DAT)= Days After Transplant, S.E = Standard error, C.V = Coefficient of variation.

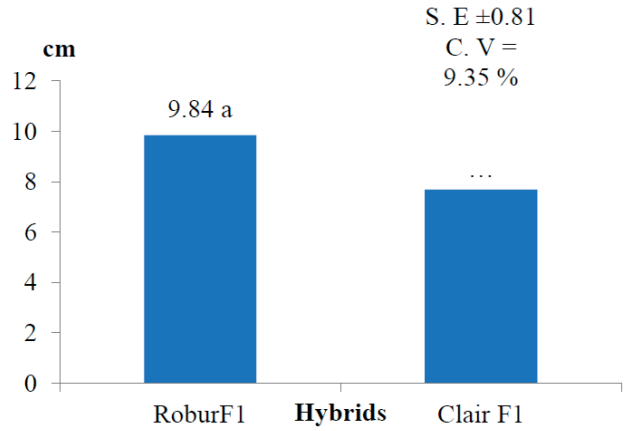



**Figure 3.** Length of internodes 45 days after transplant. (a, b) Treatments with the same letter are not significantly different by t-Student test (p≤0.05).
SE = Standard error, CV = Coefficient of variation.

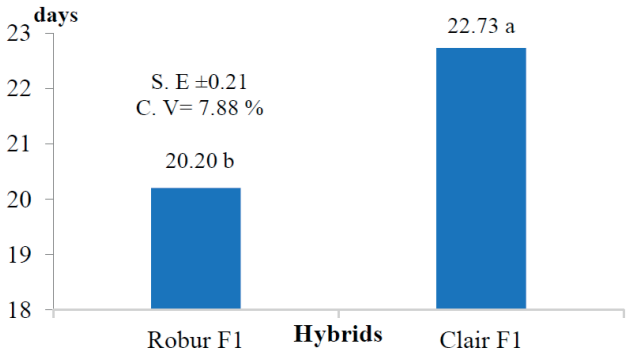



**Figure 4.** Number of days to flowering in pepper hybrids. (a, b) Treatments with the same letter are not significantly different by t-Student test (p≤0.05).
SE = Standard error, CV = Coefficient of variation.

statistically significant differences (p< 0.05) concerning the Robur F1 hybrid (212.06 g). Higher agricultural yield was obtained in Clair F1 (6.87 kg/m$^2$) with statistically significant differences with respect to Robur F1 (5.36 kg/m$^2$) (Table 1).

Regarding the variable number of fruit per plant, Depestre[24] in the evaluation of 32 F1 Cuban hybrids of pepper in protected cultivation in the optimal period, obtained higher values than those obtained in this research, which ranged between 13.0 and 33.1.

Regarding these variables, in the scientific literature consulted no reports were found on the hybrids evaluated; however, Estrada[25] affirmed that the size of the fruit and its firmness are essential characteristics for commercialization. Moreno[26] evaluated 13 pepper hybrids under protected cultivation and reported values for the average fruit weight of 140.7 g, lower than those obtained in this investigation.

Evaluating the number of fruits per pepper plant is a genetically useful trait for selecting the most productive hybrids under natural and protected production systems[27]. Similarly, prediction of pepper yield potential includes determining the number of fruits per plant and some researchers considered it the most significant variable with a positive effect on the yield of pepper fruit yield[28].

According to the pepper descriptor (IPGRI, AVRDC and CATIE, 1995), 10 average fruit yield weight should be determined in at least 30 plants, but in our study, 60 fruits were recorded at random. Similarly, Gebru[29] found differences in average weight of the fruit of green pepper under clay pot and furrow irrigation methods.

The yields of the Clair F1 and Robur F1 hybrids obtained in this investigation were lower than those reported by Pashold and Zengerle[30] in Germany, which obtained yields of 20 kg/m$^2$, determining the right moment for irrigation using tensiometers. Villamil[31] reported yields in the order of 17 kg/m$^2$ with a method based on solar radiation. This author stressed that you can obtain yields between 18 and 22 kg/m$^2$ in high-tech greenhouse, while yields of up to 12 kg/m$^2$ in low-tech greenhouse and meshes.

Casanova[32] highlighted that performing correct cultural tasks (pruning and vertical handling) can achieve yields of 10 and 11 kg/m$^2$ with a planting density of 2.3-2.5 plant/m$^2$. Some author preferred evaluation of agricultural yield and their components to determine which pepper hybrids are adaptable to local climatic conditions[33]. Organic growers of pepper preferred hybrids with higher agricultural yield because it results in better prices[34]. Mamedov[35] maximized the economic efficiency of sweet peppers' domestic hybrids in the steppe zone conditions by selecting the most promising agricultural yield varieties.

| Hybrids | Number of fruits per plant | Average fruit weight (g) | Agricultural yield (kg/m$^2$) |
|---|---|---|---|
| Robur F1 | 10.0 b | 212.06 b | 5.36 b |
| Clair F1 | 12.6 a | 273.60 a | 6.87 a |
| S. E (±) | 0.215 | 2.39 | 0.07 |
| CV (%) | 15.10 | 8.25 | 2.5 |

(a, b) Treatments with the same letter are not significantly different by t-Student test (p≤0.05)

SE = Standard error, CV = Coefficient of variation

**Table 1.** Average fruit weight, number of fruits per plant and fruit yield in bell pepper hybrids.

**Pericarp thickness, length of the fruit and fruit top width**

Greater pericarp thicknesses were observed in Clair F1 (6.5 mm) with statistically significant differences ($p < 0.05$) respect to Robur F1 hybrid (4.6 mm). Robur F1 hybrid had larger fruits (13.0 cm) respect Clair F1 (9.4 cm) with statistically significant differences ($p < 0.05$) and pepper fruits Clair F1 were significantly wider (8.3 cm) respect Robur F1 hybrid (7.5 cm) (Table 2).

The results of this work related to pericarp thickness differ from those reported by Hernández[36] in Mexico, who obtained values of 8.54 mm for the Mecate F1 pepper hybrid under technified greenhouse conditions. This author indicated this variable's importance in selecting pepper cultivars with fleshy pericarp for consumption as a vegetable.

Similarly, Sharma[37] found fruit yield per plant had a positive and significant association with pericarp thickness, similar to this result. In organic pepper plots, a greater mean of pericarp thickness (5.05 mm) means more quality. It is one of the important parameters in the processing of Capia pepper because thicker fruits had higher mean values for total soluble solids[38]. Some authors considered that a pepper cultivar with thicker pericarps may have heavier fruits and better post-harvest conservation[39]. Pericarp thickness is desirable, giving fruit firmness and better quality for fresh market[40].

Concerning the length of the fruit, our results were superior to those recorded by Moreno[41], who evaluated 13 pepper hybrids under protected cultivation, obtaining a general average of 6.8 cm. Similarly Depestre[25] indicated that the longest fruits are not the heaviest or widest fruits, and our results are similar. The length of fruit may varied according with the level of urea by foliar applications[42], plant densities[43] and efficiency of irrigation system[44]. In Cuba, traditional preferences of the consumer are focused on larger pepper fruits.

The results of fruit top width were wider than those obtained by Moreno[27], who evaluated 13 hybrids of peppers under protected cultivation for which they reported a general average of 8.1 cm. According to *Capsicum spp* descriptor, fruit width must be measured at the widest point, and 10 ripe fruits of the second harvest should be evaluated[10]. In our work, 20 fruits of each hybrid were chosen randomly in the second harvest. Similar to our results, Gangadhara and Badiger[45] indicated that fruit width in bell peppers was positively related to fruit quality traits like fruit length, weight, and number of fruits per plant. They proposed that the fruit width trait is predominantly governed by non-additive variance. Kaur[46] observed significant and desirable heterosis in fruit width over better parent and standard checks of pepper lines, arguing this variable's importance for pepper fruit quality selection.

**Color of the fruit**

Robur F1 and Clair F1 showed red at ripening but were green just before the ripening stage (Figure 5).

The type and content of chlorophyll, carotenoids, and flavonoids[47] determine the color of pepper fruit. *Capsicum* species are rich in different fruit colors, changing during each developmental stage. At the immature period, fruits may be white, green, purple or black. When completed, fruits gradually change to yellow, orange, red and brown[48]. The difference in the color of pepper fruit is mainly due to the differential accumulation of flavonoids and carotenoids[49]. In our study, not any determination of these metabolites was determined.

**Shape of the fruit**

Clair F1 adopted the Blocking shape, while and Robur F1 had Lamuyo shape (Figure 5).

The evaluation of the shape of fruit in peper is very important for selecting a genotype with a resistance level to *Phytophthora capsici*[50]. In Cuba, consumers prefer typical large bell peppers used as salad. The shape and pericarp thickness of pepper fruits are the principal traits to be evaluated for cultivar selection.

**Number of lobes per fruit**

Clair F1 presents three lobes per fruit, while Robur F1 has four (Figures 6 and 7).

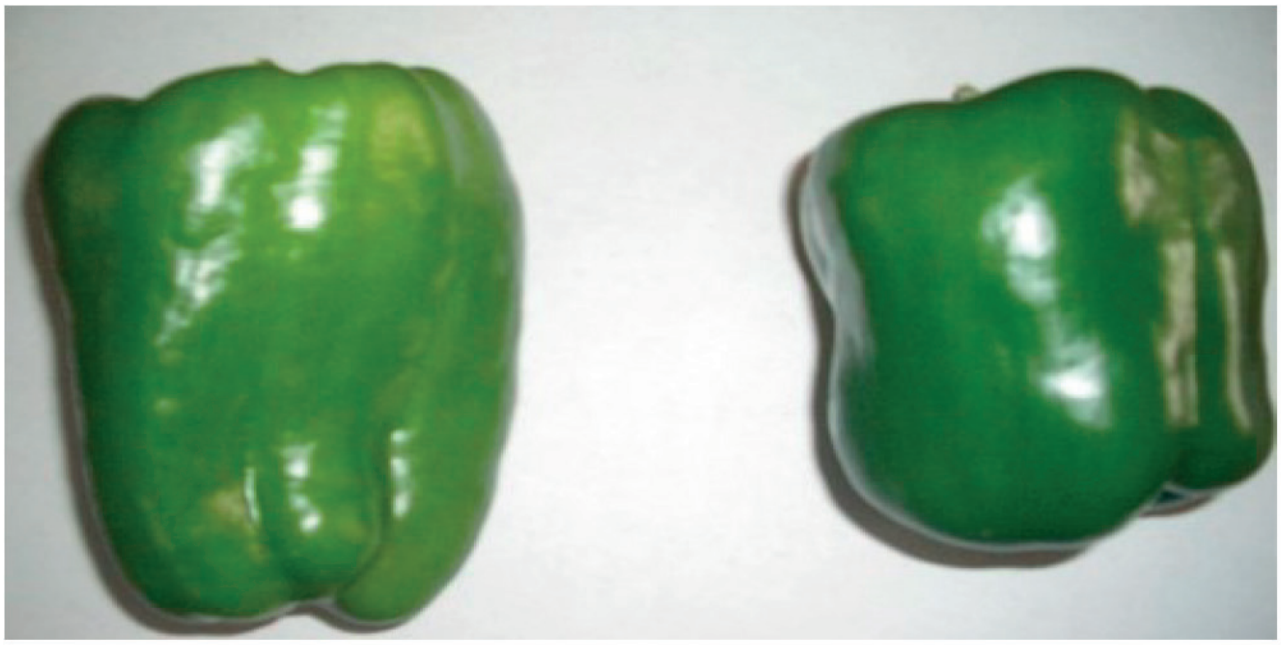
These results agree with those obtained by Silva[51], who mentioned the number of lobes in pepper may oscillate between 3 and 4. Several lobes are considered to have a positive indirect effect on yield via gaining fruit weight.

| Hybrids | Pericarp thickness (mm) | Length (cm) | Fruit top width (cm) |
|---|---|---|---|
| **Clair F1** | 6.5a | 9.4 | 8.3a |
| **Robur F1** | 4.6b | 13.0a | 7.5b |
| **SE (±)** | 0.17 | 0.29 | 0.07 |
| **C. V (%)** | 10.1 | 15.5 | 12.2 |

(a, b) Treatments with the same letter are not significantly different by t-Student test ($p \leq 0.05$)

SE = Standard error, CV = Coefficient of variation

**Table 2.** Fruit dimensions in two bell pepper hybrids.



A. Robur F1 (Lamuyo) B. Clair F1 (Blocking)

**Figure 5.** Fruit shape in pepper hybrids.

**Figure 6.** Number of lobes in Clair F1 fruits.

Results obtained in our research provide essential information on the agro-productive response of pepper hybrids of recent introduction in Cuba under the intensive production system of protected crops. Both hybrid openings may improve production systems under tropical sheltered production systems, increasing agricultural yields.

## Conclusions

Height and diameter of the main stem, length of internodes and days to flowering in 'Robur F1' were more significant compared to the 'Clair F1' hybrid. The highest fruit yields were recorded in 'Clair F1'. 'Clair F1' had greater pericarp thickness, while 'Robur F1 fruit were longest. In both hybrids, green color prevailed, with Blocking and Lamuyo shapes and three to four lobes per fruit. Both hybrids may be utilized under the Cuban tropical sheltered production system.

### Author Contributions

Conceptualization, Alexander Bernal Cabrera and Michel Leiva Mora; Methodology, Alexander Bernal Cabrera, Michel Leiva Mora and Yosbel Lazo; software, Michel Lei-

**Figure 7.** Number of lobes in Robur F1 fruits.

va Mora, validation, Justo A. Rojas Rojas, Hugo Alejandro Castro Alban, Sandra Soria Re; formal analysis, Alexander Bernal Cabrera, Sandra Soria Re and Michel Leiva Mora; investigation, Alexander Bernal Cabrera, Hugo Alejandro Castro Alban; resources, Alexander Bernal Cabrera; René Nazareno Ortíz, Hugo Alejandro Castro Alban and Michel Leiva Mora, data curation, Jorge Antonio Freile Almeida and Michel Leiva Mora; writing-original draft preparation, Alexander Bernal Cabrera, Michel Leiva Mora and Yosbel Lazo Roger; writing-review and editing, Justo A. Rojas Rojas, Jorge Antonio Freile Almeida and René Nazareno Ortíz; supervision, Alexander Bernal Cabrera; All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest**

The authors declare no conflict of interest.

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