Physiological Characterization of Manzano Hot Pepper (*Capsicum pubescens* R & P) Landraces

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ABSTRACT. Six manzano hot chile pepper landraces (*Capsicum pubescens* R & P) were evaluated to identify genotypes which might contribute toward obtaining superior hybrids by providing the following characteristics: low height, short internodes, rapid biomass accumulation, high harvest index, high fruit quality, and high photosynthetic rate. The landraces studied were 'Chiapas', 'Huatusco I', 'Huatusco II', 'Perú', 'Puebla', and 'Zongolica'. Plants were grown in a shaded glasshouse for 9 months, with drip irrigation. Growth, biomass distribution, fruit quality and yield were determined. All varieties exhibited advantageous characteristics, i.e., large fruit (60 mL) with thick pericarp (4.2 mm) in 'Puebla'; short internodes (10 cm) in 'Zongolica' and 'Huatusco II'; high harvest index (0.24), high yield (18 to 19 t·ha⁻¹) and high relative growth rates (0.12 g·g⁻¹·d⁻¹) in 'Perú' and 'Puebla'; and high dry mass accumulation (450 g/plant) in 'Chiapas'. The highest photosynthesis rate in manzano hot pepper was 7.7 μmol of CO₂/m²/s at 500 μmol photons/m²/s, in 'Zongolica' and 'Puebla'.

Manzano hot chile pepper (*Capsicum pubescens* R & P) is a perennial plant that originated in the South American highlands of Bolivia, Perú and Chile. It was introduced into México at the beginning of the 20th century. This pepper is cultivated as an annual crop in small orchards associated with fruit trees for support and shading, at altitudes between 1700 and 2400 m (Pérez and Castro, 1998). It exhibits phenotypic variability regarding plant and fruit characteristics which are desirable in the initiation of a pepper breeding program. The yellow, apple-shaped fruit (three to four locules) are generally preferred over the orange or red, pear-shaped fruit (one to two locules).

Based on the increasing demand for this species in México and the United States, an intensive production system as an annual crop was developed for greenhouse conditions (Pérez and Castro, 1998). The evaluation of agronomic and physiological characteristics of existing landraces should help in the development of improved manzano varieties. Superior hybrids must produce high yields of high quality marketable fruit, have multiple insect and disease resistances, and exhibit a wide range of adaptability.

This research was initiated to evaluate physiological characteristics of six manzano hot pepper landraces to provide breeders with useful information for developing improved cultivars. An adequate physiological characterization can be achieved through plant growth analysis. According to Hunt (1990), this analysis allows the quantification of the joint effects of environmental and genetic factors influencing the production and distribution of dry mass during the growing season. It requires periodic measurements of the plant's dry mass (DM) and leaf area (LA). With these data, growth efficiency indices of whole plants and their organs can be calculated, as well as the relationship between the assimilation apparatus and dry mass production (Evans, 1972).

Plant breeders use genotypic yield differences to carry out the selection process (Wallace et al., 1972). Since yield is a complex

polygenic trait, plant breeding may be simplified by selecting simpler traits, such as fruit size and number (yield components), and physiological traits like LA, DM, and efficiency indices such as growth rate (GR), relative growth rate (RGR), etc. (Peña et al., 2002).

About 95% of the plant's dry mass is made up of carbon compounds, so that fruit yield is closely linked to the net photosynthetic rate and to the subsequent photoassimilate distribution among the different organs in the plant (Gifford et al., 1984). In annual crops, Lambers and Porter (1992) estimated that >50% of the net CO₂ fixed by the leaves could be lost through respiration, and the energy required for cell maintenance might represent half of the whole plant respiration. There is also evidence that increments in the crop growth rate and yield are associated with low respiration rates (Gifford et al., 1984).

The present research work was focused on the physiological characterization of six manzano hot chile pepper landraces with contrasting fruit, leaf and stem morphology, as a basis to identify genotypes to produce superior hybrids.

Materials and Methods

EXPERIMENTAL SETUP. The study was conducted from March 2000 to February 2001 in a glasshouse of the Universidad Autónoma Chapingo, at Chapingo, México. Seeds of each population were planted according to the intensive production system proposed by Pérez and Castro (1998). This system includes drip irrigation with Steiner's universal nutrient solution (Steiner, 1984), whose pH is adjusted to 5.5 with sulfuric acid. In addition, the system includes a 50% shading with a plastic mesh, and red gravel, locally named *red tezontle*, as a substrate, contained in black polyethylene bags (40 cm in diameter and 45 cm in height). Potted plants were arranged in rows 80 cm apart and 50 cm between them. Environmental conditions fluctuated during the growing season from 20/10 to 25/12 °C day/night temperature, 500 to 550 μmol of photons/m²/s at midday, 11 to 13 h photoperiod, 60% to 75% relative humidity; and 330 to 400 $\mu\text{L}\cdot\text{L}^{-1}$ of CO₂ concentration.

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PLANT MATERIALS. Six manzano landraces, five representing the Mexican genotypes and one from Perú, were included in this study. Three of them are from two locations in the State of Veracruz, Huatusco ('Huatusco I and II') and Zongolica ('Zongolica'). These three cultivars have medium-sized yellow fruit, varying in shape from pear to apple-shaped. The cultivar from Tlalahuiquitepec, Puebla ('Puebla') has long internodes, large leaves, and large red, yellow to orange-colored and apple-shaped fruit. The fifth cultivar, obtained from San Cristóbal de las Casas, Chiapas ('Chiapas'), has tall plants (>3 m) and red fruit. The sixth variety, from Lima ('Perú'), has short internodes with red or yellow pear- and apple-shaped fruit.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS. The experimental design was completely randomized with 60 replicate plants for each cultivar. Three replicate plants randomly selected per cultivar were harvested every month for growth analysis. Statistical analysis included analyses of variance and Tukey's multiple range test ($\alpha = 0.05$), performed with the SAS statistical software (SAS, 1996).

GROWTH ANALYSIS. Three whole plants per cultivar were collected at 30-d intervals during 9 months to obtain dry mass of roots, stems, leaves and fruit. Plants were oven-dried (Precision 17 GCA Corp.) at 70 °C until they reached constant weight. Fruit quality characteristics were determined in 10 fruit per plant for fruit size (volume in mL), pericarp thickness (mm), number of seeds and locules per fruit. The number of leaves (LN) and leaf area (LA) per plant were determined for the same plants, with an area integrator (LI-3100; LI-COR Inc., Lincoln, Nebr.). For growth, the LA and DM data were plotted versus time. The last sampling date was used to calculate the harvest index (fruit DM/whole plant DM). The mean leaf size (whole plant LA/number of leaves) was calculated for each month.

The equations used to calculate growth rate (*GR*) and relative growth rate (*RGR*) were (Hunt, 1990) as follows:

$$GR = \frac{(W_2 - W_1)}{(t_2 - t_1)} \quad \text{Eq. [1]}$$

where *GR* = mean growth rate, in g·d⁻¹ of DM; *W*₁ and *W*₂ = total plant dry weights at the beginning (*t*₁) and at the end (*t*₂) of one sampling interval, in days.

$$RGR = \frac{(\ln W_2 - \ln W_1)}{(t_1 - t_2)} \quad \text{Eq. [2]}$$

where *RGR* = mean relative growth rate, in g·g⁻¹·d⁻¹; *LnW*₁ and *LnW*₂ = natural logarithms of the total plant dry weights at the beginning (*t*₁) and the end (*t*₂) of one sampling period.

DAILY NET PHOTOSYNTHETIC RATE. Instantaneous CO₂ net assimilation rate (μmol of CO₂/m²/s) was measured in the youngest mature leaf of each plant from 0900 to 1800 HR, at 2-h intervals, with a portable gas analyzer (LI-6200; LI-COR). Such a leaf corresponds to the fourth leaf of the main stem, counting from the top. The readings were obtained in the fourth month after planting, when plants started to bloom.

Results

TOTAL BIOMASS. Manzano hot pepper is a late maturing species taking up to 9 months to complete a fruiting cycle. In contrast, other hot pepper varieties grown throughout México such as 'Jalapeño', 'Serrano', 'Ancho', 'Pasilla', and 'Guajillo', members of the *Capsicum annuum* L. species, have a maturity cycle of 4 to 5 months. All manzano landraces showed little dry mass

accumulation (Fig. 1) and slow growth rate (Fig. 2) during the first 3 months. An average of 13 g of biomass accumulated in this period, equivalent to 4% of the total biomass (350 g/plant) at the end of cycle. However, the highest relative growth rates in all landraces were observed at 90 d after planting, particularly in 'Huatusco I', 'Puebla', and 'Perú', with values between 0.12 and 0.14 g·g⁻¹·d⁻¹ (Fig. 3).

Thereafter, plant growth increased following a sigmoid pattern. 'Chiapas' accumulated the highest biomass while 'Puebla' had the

Fig. 1. Dry-mass accumulation in six manzano hot pepper cultivars growing under glasshouse conditions. Means (*n* = 3) with the same letter in the last month are statistically equal (Tukey, 0.05).

Fig. 2. Growth rate in six manzano hot pepper landraces growing under glasshouse conditions (*n* = 3).

Fig. 3. Relative growth rate (*RGR*) in six manzano hot pepper cultivars growing under glasshouse conditions. Means (*n* = 3) with the same letter in the same date are statistically equal (Tukey, 0.05).

Table 1. Harvest index and relative biomass distribution at the ninth month in six manzano hot pepper landraces.

Landrace	Biomass distribution [g (%)]				Harvest index
	Root	Stem	Leaves	Fruit	
Zongolica	61 (17) a ^z	180 (50) bc	84 (24) ab	33 (9) b	0.09 b
Huatusco II	44 (12) bc	201 (53) b	96 (25) a	40 (10) b	0.01 b
Puebla	28 (9) d	145 (44) d	76 (24) bc	75 (23) a	0.23 a
Huatusco I	37 (10) cd	169 (48) cd	82 (23) ab	68 (19) a	0.19 a
Peru	41 (12) bc	147 (45) d	63 (19) c	79 (24) a	0.24 a
Chiapas	50 (11) b	288 (65) a	84 (19) ab	24 (5) c	0.05 c
cv ^y (%)	10	12	18	22	20

^zMeans (n = 3) with the same letter in the same column are statistically equal (Tukey, 0.05).

^ycv = coefficient of variation.

Fig. 4. Leaf area growth in six manzano hot pepper cultivars growing under glasshouse conditions. Means (n = 3) with the same letter in the last month are statistically equal (Tukey, 0.05).

lowest (Fig. 1). The maximum *GRs* were reached by ‘Huatusco II’ and ‘Zongolica’, with 5.2 and 5.8 g·d⁻¹ of dry mass, at 240 d after planting (Fig. 2), when their *RGRs* had low values of about 0.02 g·g⁻¹·d⁻¹ (Fig. 3).

Table 2. Monthly average number of leaves per plant in six manzano hot pepper landraces.

Landrace	Month ^z								
	June	July	August	September	October	November	December	January	February
Zongolica	3 b	5 a	18 c	80 c	158 b	360 ab	493 bc	566 ab	483 bc
Huatusco II	3 b	7 a	14 c	80 bc	148 b	236 c	557 b	616 a	664 a
Puebla	3 b	5 a	24 bc	73 c	148 b	282 b	586 ab	398 c	440 c
Huatusco I	3 b	7 a	33 b	137 a	250 a	311 ab	608 a	608 a	560 ab
Perú	5 a	7 a	29 b	128 ab	239 ab	276 b	340 c	500 bc	512 bc
Chiapas	3 b	8 a	47 a	130 a	253 a	380 a	528 bc	606 a	566 ab
cv (%) ^y	13	19	13	15	20	18	19	14	16

^zMeans (n = 3) with the same letter in each row are statistically equal (Tukey, 0.05).

^ycv = coefficient of variation.

Table 3. Monthly averaged leaf size per plant, expressed in square centimeters, in six manzano hot pepper landraces.

Landrace or cultivar	Month ^z								
	June	July	August	September	October	November	December	January	February
Zongolica	7 b	7 b	35 a	28 b	27 a	32 a	34 a	31 a	32 b
Huatusco II	8 ab	8 ab	41 a	30 b	34 a	42 a	33 a	40 a	45 a
Puebla	7 b	8 ab	42 a	58 a	34 a	42 a	33 a	40 a	38 ab
Huatusco I	7 b	7 b	40 a	27 b	33 a	36 a	35 a	40 a	42 a
Perú	7 b	9 ab	37 a	34 b	31 a	43 a	39 a	36 a	38 ab
Chiapas	12 a	12 a	36 a	32 b	38 a	40 a	38 a	45 a	44 a
cv (%) ^y	8	18	23	18	19	12	15	14	7

^zMeans (n = 3) with the same letter in each row are statistically equal (Tukey, 0.05).

^ycv = coefficient of variation.

BIOMASS DISTRIBUTION. The stem was the organ with the highest dry mass accumulation, representing from 44% to 65% of the total biomass; it was followed by leaves, fruit and roots (Table 4). Consequently, the harvest indices were lower than in most crops, fluctuating between 0.05 in ‘Chiapas’ to 0.23 and 0.24 in ‘Perú’ and ‘Puebla’ (Table 1).

LEAVES. As with biomass, leaf area growth was negligible in all genotypes during the first 90 d (Fig. 4). Landraces ‘Chiapas’, ‘Huatusco I’, ‘Puebla’ and ‘Zongolica’ reached their maximum leaf area in 8 months, while ‘Huatusco II’ and ‘Perú’ continued increasing throughout the ninth month.

By the end of the growing season, ‘Huatusco II’, ‘Chiapas’, and ‘Huatusco I’ had the largest leaf areas (2.9, 2.5, and 2.3 m² per plant, respectively), the highest number of leaves (664, 566 and 560, respectively), and the largest leaf sizes (45, 44, and 42 cm², respectively), (Tables 2 and 3). The mean leaf size tended to remain constant after the third month, so that it can be considered as a stable trait in this species. Consequently, the differences in leaf area among genotypes were largely determined by the number of leaves rather than by leaf size.

STEM. There were no significant differences among landraces in main stem diameter, measured just below the first bifurca-

Table 4. Means of plant height, internode length, and stem diameter in six manzano hot pepper landraces, nine months after planting.

Landrace	Plant ht ^z (m)	Internode length ^{z,y} (cm)	Main stem diam ^{z,x} (cm)
Zongolica	2.9bc ^z	11.3b	1.3a
Huatusco II	2.6c	11.1b	1.1a
Puebla	3.1ab	11.7b	1.1a
Huatusco I	2.8bc	10.8b	1.1a
Peru	2.7bc	10.8b	1.2a
Chiapas	3.4a	14.0a	1.1a
cv (%) ^w	4.7	6.8	8.8

^zMeans (n = 3) with the same letter in each column are statistically equal (Tukey, 0.05).

^yMain branch.

^xMeasured just below the first node.

^wCV = coefficient of variation.

Table 5. Comparison of means of variables used to measure fruit quality and yield in six manzano hot pepper landraces.

Landrace	Fruit/ plant ^z (no.)	Fruit vol ^z (mL)	Pericarp thickness ^z (mm)	Yield ^{z,y} (t·ha ⁻¹)
Zongolica	10.3 ab ^z	33.7 b	2.7 b	8.27 b
Huatusco I	14.3 ab	38.1 b	2.7 b	8.42 b
Puebla	21.3 ab	60.0 a	4.2 a	17.87 ab
Huatusco II	21.3 ab	35.7 b	2.8 b	14.37 ab
Peru	34.7 a	36.7 b	2.4 b	19.25 a
Chiapas	5.7 b	40.1 b	2.9 b	4.03 c
cv ^x (%)	37	14	18	41

^zMeans (n = 3) with the same letter in each column are statistically equal (Tukey, 0.05).

^yDensity of 18 000 plants/ha.

^xCV = coefficient of variation. 0.05).

Fig. 5. Daytime pattern of photosynthesis in six manzano hot pepper cultivars. Means (n = 3) with the same letter in each hour are statistically equal (Tukey, 0.05).

tion (Table 4). However, there were differences in plant height, since 'Chiapas' had the tallest plants (3.4 m) because of its long internodes (14 cm), while 'Huatusco II' had the shortest plants (2.6 m) and short internodes (11.1 cm).

FRUIT QUALITY AND YIELD. Table 5 shows that 'Puebla' produced the largest fruit (60 mL) with thickest pericarp (4.2 mm), thus achieving a high rank in fruit yield with 17.8 t·ha⁻¹, although it was intermediate in fruit number (21.3 fruit per plant). Landrace

'Perú' had the highest fruit yield (19.2 t·ha⁻¹) because of its highest fruit number (34.7 fruit/plant), even though its fruit size was small (36.7 mL). Both 'Puebla' and 'Perú' yielded well above the 7 to 8 t·ha⁻¹ registered in commercial orchards by Pérez and Castro (1998). The numbers of locules per fruit and seeds per fruit, whose mean values were 2.8 and 40, respectively, did not vary significantly among cultivars (data not shown).

PHOTOSYNTHETIC DAYTIME PATTERN. Photosynthetic rates varied during the day (Fig. 5), with maximum values occurring between 1100 and 1300 HR. The highest rates, under glasshouse and 50% shading conditions, were found in 'Zongolica' and 'Chiapas', with 7.7 and 7.2 μmol of CO₂/m²/s, respectively, whereas the lowest rates (4.3 μmol of CO₂/m²/s) occurred in 'Puebla'.

Discussion

The factors determining the source strength in crops are the active leaf area and the net photosynthetic rates (Priol and Schwebel-Dugu, 1992). Considering the high leaf areas observed for the six landraces (ranging from 1.5 to 2.9 m²/plant), it may be inferred that leaf area is not the main factor limiting the source strength in manzano hot pepper (Fig. 4). In maize (*Zea mays* L.) the lack of grain formation in secondary ears was more related to assimilate transport deficiencies and lower assimilate demand, than to leaf area (Mendoza et al., 2000). In addition, two of the landraces with the lowest leaf area, Puebla and Zongolica (Fig. 4), had high fruit yield and harvest index, thus showing a better photoassimilate use efficiency. In contrast, Chiapas was the tallest plants with the most abundant foliage, the highest total biomass accumulation and the second highest net photosynthetic rate, but had the least fruit yield (Table 5). It appears that in manzano hot pepper the photosynthesis rate is more related to plant growth and dry mass accumulation than to biomass distribution and fruit yield.

According to the harvest indices shown by these genotypes (Table 1), only 24% of the fixed carbon is used for fruit growth in 'Peru', the highest yielding landrace. In order to increase this species yield potential it would be necessary to improve its harvest index, as suggested by Gifford et al. (1984). For example, in winter wheat (*Triticum aestivum* L.) the gains in grain yield of the varieties developed in England over 70 years are mostly due to increases in the harvest index, rather than to increments in dry mass production. In this regard, Gifford et al. (1984) suggest that to raise the harvest index it is necessary to reduce an excessive vegetative growth and to increase the net photosynthetic rate per unit leaf area.

Based on the growth characteristics of the six manzano hot pepper landraces in a breeding program, 'Chiapas' is expected to supply a high growth rate and a greater photosynthetic apparatus size, which would result in a maximum accumulation of total biomass. 'Peru', 'Puebla', and 'Huatusco I' could contribute high relative growth rate, fruit yield and harvest index values, while 'Huatusco II' and 'Zongolica' would contribute a lower plant height with short internodes. In theory, in the absence of unfavorable pleiotropy and strong linkage among desirable genes, it might be possible to obtain intervarietal hybrids of intermediate height, high dry mass accumulation, earliness and high harvest index, appropriate for an intensive production system where space is limited, but without restrictions in water and nutrient availability. As for fruit quality, 'Puebla' should be the best parent because of its largest fruit and thickest pericarp, in addition to a high yield (Table 5).

Under glasshouse conditions and $500 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ of photosynthetically active radiation, the highest net photosynthesis rate in *Capsicum pubescens* was $7.7 \mu\text{moles of CO}_2/\text{m}^2/\text{s}$, which occurred between 1100 to 1400 HR (Fig. 5). This rate is 23% to 30% smaller than the maximum rates registered in *C. annuum* bell pepper (10 to $11 \mu\text{mol of CO}_2/\text{m}^2/\text{s}$) grown under greenhouse conditions with a photon flux density of 400 to $700 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Turner and Wien, 1994). However, manzano hot pepper produces more leaves (500 to 600) and leaf area (1.6 to 2.9 m^2) per plant than bell pepper, which only had 0.6 m^2 leaf area when grown in similar glasshouse conditions (Wien, 1997).

In these conditions and at a plant population equivalent to $18,000$ plants per hectare, manzano plants grew tall, at least 2.6 m , thus requiring strong physical supports to keep them erect. In addition to the selection of genotypes with short internodes and lower height, such as landraces 'Peru' and 'Zongolica', to facilitate their management and harvesting, another practical way to shorten manzano plants to 1.8 m tall is to trim the stem apices and pruning lateral buds and branches.

Conclusion

The physiological and agronomic variations observed among these six manzano hot pepper landraces allow us to propose an ideotype for an intensive production system under greenhouse conditions. This ideotype should have a high relative growth rate at the vegetative stage, intermediate or low values of growth rate and leaf area during fruit production, short internodes, large fruit with thick pericarp, and high fruit yields and harvest indices. These results are also useful in selecting parents for breeding by hybridization, and in recommending the best landraces as varieties for commercial production under that system.

Literature Cited

- Evans, C.E. 1972. The quantitative analysis of plant growth. Univ. Calif. Press, Berkeley.
- Gifford, R.M., J.H. Thorne, W.D. Hitz, and R.T. Giaquinta. 1984. Crop productivity and photoassimilate partitioning. *Science* 225:801–808.
- Hunt, R. 1990. Basic growth analysis. Unwin Hyman, London.
- Lambers, H. and H. Porter. 1992. Inherent variation in growth rate between higher plants: A search for physiological causes and ecological consequences. *Adv. Ecol. Res.* 23:188–261.
- Mendoza C.M.C., V.A. González, E.M. Engleman, and J. Ortiz. 2000. Phloem area and prolificacy in maize. *Agrociencia* 34:141–151.
- Peña, R.A., J.D. Eastin, S.D. Kachman, and D.J. Andrews. 2002. Selection response for grain yield and its components seed number and seed size in sorghum. *Rev. Fitotecnia Mexicana* 25 (1):49–56.
- Pérez G.M. and R. Castro. 1998. Guía técnica para la producción intensiva de chile manzano. Universidad Autónoma Chapingo. Chapingo, México. Boletín de Divulgación 1.
- Prioul, J.L. and N. Schwebel-Dugu. 1992. Source–sink manipulations and carbohydrate metabolism in maize. *Crop Sci.* 32:751–756.
- SAS Institute. 1996. SAS software release 6.12. SAS Inst. Inc., Cary, N.C.
- Steiner, A. 1984. The universal nutrient solution, p. 633–650. In: 6th international congress on soilless culture. Proc. Intl. Soc. Soilless Cult., Luterén, Netherlands.
- Turner, A.D. and H.C. Wien. 1994. Photosynthesis, dark respiration and bud sugar concentration in pepper cultivar differing in susceptibility to stress-induced bud abscission. *Ann. Bot.* 73:623–628.
- Wallace, D.H., J.L. Ozbun, and H.M. Munger. 1972. Physiological genetics of crop yield. *Adv. Agr.* 24:96–142.
- Wien, H.C. 1997. Peppers, p. 259–293. In: H.C. Wien (ed.). The physiology of vegetable crops. Cornell Univ., Ithaca, N.Y.