Article

Selection of outstanding papaya plants in commercial environments for breeding purposes

Juan Carlos Álvarez Hernández[1§]
Luis Mario Tapia-Vargas[2]

[1]Experimental Field Apatzingán Valley-INIFAP. Apatzingán-Cuatro Caminos Highway km 17.5, Antúnez, Parácuaro, Michoacán, Mexico. CP. 60781. [2]Experimental Field Uruapan-INIFAP. Av. Latinoamericana 1101, Col. Revolución, Uruapan, Michoacán, Mexico. CP. 60150. (tapia.luismario@inifap.gob.mx).

[§]Corresponding author: alvarez.juan@inifap.gob.mx.

Abstract

Due to market demand, in the producing regions of Mexico the dominant variety is Maradol, in different fruit quality levels, since the type of seed used varies from the original F1, to descendent selections identified as F2 to F5. The above, leads to a genotypic degeneration and segregation. In this way it is necessary an adequate selection of parents and controlled pollination for seed production, and that is adapted to the region of interest. Therefore, the objective was to select outstanding papaya plants adapted to the production area of Michoacán. Through field explorations in commercial plots, papaya plants of the Maradol hermaphrodite type and with outstanding characteristics were identified and characterized. In the plants, flower buds were selected and covered to induce self-pollination. The fruits were collected in the maturity stage and the seeds were obtained. Morphological variables of plant and fruit, health and germination were recorded. 12 orchards presented outstanding plants. The characterization of the progress in the development of floral bud to fruits was variable, since the amount of fruits formed in relation to the buds covered initially was reduced, as well as, it reduced the amount of fruits collected in relation to the fruits formed. Regarding phytosanitary status, the presence of viruses, mites and other insects was recorded in most of the registered orchards. The germination was acceptable. It was concluded that selected papaya plants were identified and characterized based on outstanding characteristics and adapted to the production area of Michoacán, for further improvement study.

Keywords: *Carica papaya* L., hermaphrodite, Maradol variety, plant sexing, seed production.

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Introduction

Mexico is located in a privileged geographical position, which is favored by environmental conditions for the development of different crops in the open field. Among the economically important crops papaya (*Carica papaya* L.), whose annual *per capita* consumption is 6.4 kg (SIAP, 2017). It is a fruit species of rapid growth and high physiological activity, is widespread in the tropical and subtropical regions of the country. According to the SIAP-SADER (2019), nationally from 2010 to 2018 the cultivated area, the total production and the yield per hectare have presented growing trends in the cultivation of papaya, from 16 261 to 17 807 ha (9.5%), 648 235 to 1 034 532 t (59.6%) and 46.49 to 58.09 t ha^{-1} (24.9%), respectively.

Also, in order of participation, the states with the largest area harvested in 2018 were Veracruz, Colima, Oaxaca, Michoacán Chiapas and Guerrero, which together totaled 15 096 ha, however, Oaxaca excels in yields with 106.7 t ha^{-1} and in Veracruz was last placed with 32.9 t ha^{-1}. Regarding the statistical record in Michoacán, it has not been stable, in the last 9 years the average cultivated area was 2 421 ±589 ha, the total yield was 55 703 ±16 247 t and the yield was 32 ±2.2 t ha^{-1} (SIAP-SADER, 2019).

Due to market demand, in the producing regions of Mexico the dominant variety is the Maradol of Cuban origin (SIAP-2017), in its different levels of fruit quality, since the type of seed used varies from the original F1 to descendent selections identified as F2 to F5. The above, leads to a genotypic degeneration and segregation. This situation is attributable to the type of pollination characteristic of papaya and influenced by its floral biology (Urasaki *et al*., 2012).

The papaya is a very complex species from the physiological point of view, and this complexity is reflected in the production of fruits, so it is important to understand the different floral aspects (Álvarez *et al*., 2018), as well as the selection of the progenitors and controlled pollination, as well as in obtaining seed, crosses must be made between hermaphroditic plants or self-pollination to obtain 66% of seeds that will originate hermaphroditic plants (Ram, 2005).

In the selection of plants for seed multiplication purposes must meet the requirements to ensure their origin and quality based on the following characteristics: be vigorous, phenotype must correspond to the desired variety, free of pests and diseases or varieties that show tolerance, minimum production of carpella fruits in hermaphrodite plants during winter, fruits of female or hermaphrodite, present characteristics that allow to determine what is an optimal production, locate at low height, must obtain a minimum production of sterile female flowers at the end of summer and early autumn or during dry periods, be uniform, both the size and shape of the fruit (SNICS-SAGARPA, 2014).

Therefore, it is necessary to rescue genetic material that can be used in the improvement of papaya for seed production, but also adapted to the region of interest (SNITT-SAGARPA, 2016). The agro-food chain of papaya faces difficulties associated with the low capacity for innovation and development, dependence on the production of seeds from the foreign market and, in addition, almost the entire production depends only on the Maradol variety.

Framed in the philosophy of intensive horticulture, the strategy is based on achieving higher yields per cultivated area in order to increase levels of productivity and competitiveness (Kleiber *et al*., 2012). Based on the foregoing, the objective was to select genotypes of papaya in commercial orchards with outstanding characteristics and adapted to the production area of Michoacán.

Materials and methods

Through field explorations in commercial plots of the Valley of Apatzingán, Michoacán during the months of March to December 2018, papaya plants of the Maradol type were identified. The characteristics were based on identifying plants with healthy visual appearance and excellent vigor, hermaphroditic sex, height at the first flower below 0.8 m and precocity in fruit production.

In each selected plant, at least four flower buds were chosen next to the floral opening, in order to ensure that there is no contamination or cross-pollination, these were covered with a waxed paper bag and labeled. The process of development of the fruits until physiological maturity took approximately 5 months and were collected for seed extraction and conditioning; through, wash for next germination study. Germination was based on soaking the seed in water for three days, and the floating seed, considered as vain seeds, was eliminated.

The rescued seed was placed in moist flannels and kept at room temperature (27 ±3 ºC). In addition, the level of health of the plants was contemplated, by visual exploration the presence/absence of pest insects was recorded under randomized sampling in the plants adjacent to the outstanding plants, this to anticipate some degree of tolerance or resistance.

The registered variables were: characterization of the sites using equipment and specialized literature, percentage of fruits formed and fruits collected on the flower buds covered initially; presence and absence of viruses and major pests of papaya, height of plant, the first fruit and stem circumference and fruits per plant in the harvest stage. Fruits collected were recorded polar and equatorial circumference, fruit weight, pulp width, soluble solids with refractometer and firmness with manual penetrometer and yield estimation per plant.

In relation to the germination, knowing the initial number of seed and by difference the vain seed was registered and later the germinated seed. The data recorded were analyzed with descriptive statistics, while the germination test was percentage.

Results and discussion

28 commercial orchards were explored in four municipalities of the Valley of Apatzingán Michoacán, in some orchards no outstanding plants were identified, because regardless of the surface, this did not guarantee their presence, so only 12 orchards presented this type of plants in localities corresponded to the municipalities of Paracuaro and Tepalcatepec. The location and altitude followed a common pattern in turn, the surfaces and genotypes of the orchards were variable, as well as the record of plants, buds and fruits (Table 1).

Table 1. Characterization of commercial papaya orchards and condition of selected plants.

Id.	Municipality	Location	Latitude north	Longitude west	Altitude (m)	Area (ha)	Genotype	Selected plants (num.)	Protected buds (num.)	Fruits formed (num.)	Quality fruits (num.
HP3	Paracuaro	Antunez 'La pista'	19°00'15''	102°13'00''	376	10	Maradol	3	10	1	1
HP4	Paracuaro	Antunez 'La perla 1'	19°00'15''	102°13'00''	305	7	Maradol	3	12	5	2
HP5	Paracuaro	Antunez 'La perla 2'	18°57'08''	102°13'40''	310	8	Maradol	4	12	7	2
HP6	Paracuaro	Antunez 'La perla 3'	18°56'17''	102°14'01''	315	13	Maradol	4	12	9	2
HP7	Paracuaro	Antunez 'Y griega'	18°56'12''	102°14´05''	308	10	Maradol	3	10	6	2
HP8	Paracuaro	Antunez 'La soledad'	18°58'34''	102°12'22''	322	10	Maradol	3	9	5	2
HP10	Paracuaro	Antunez 'Piedra Parada'	18°57'52''	102°15'20''	334	13	Maradol	3	9	4	1
HP11	Paracuaro	Antunez 'Pando'	19°02'00''	102°12'35''	381	4	Maradol	3	10	6	1
HP13	Paracuaro	Los Pozos	18°56'01''	102°13'05''	300	7	Maradol	3	7	4	1
HP14	Paracuaro	1º. de septiembre	18°51'51''	102°11'04''	300	6	Maradol	3	9	4	1
HT2	Tepalcatepec	Taixtan	19°07'58''	102°50'42''	354	6	Maradol	2	8	3	1
HT7	Tepalcatepec	Milanes	19°08'57''	102°51'38''	366	8	Guajira	2	6	4	1

Similarly, Table 2 presents the percentage values reached of the fruits formed and the fruits collected; that is, the fruits of quality. As it is appreciated, during the development it reduced the amount of fruits formed in relation to the covered buds, as well as, reduced the amount of fruits collected in relation to the fruits formed, due to factors of nature that influenced the process, with this, the fruits with quality except for the HP3 orchard, the rest of the orchards, presented percentages less than 50% of fruits collected.

Table 2. Process cycle floral buds to collected fruits and phytosanitary and morphological characterization of outstanding papaya plants.

Id.	(%) of formed fruits/covered buds	(%) of fruits collected/fruits formed	Presence (+) / absence (-)				Plant height (cm)	Stem circumference (cm)	Height at first fruit (cm)	Fruits per plant (no.)
			Virus	Mites	Chicharrite	Other insects				
HP3	10	100	+	+	-	+	190	31	47	34
HP4	41.7	40	+	+	-	+	187	36	45	30
HP5	58.3	28.6	+	-	-	-	166	34	52	27
HP6	75	22.2	-	+	-	-	159	33	44	32
HP7	60	33.3	+	+	-	+	187	29	37	30
HP8	55.6	40	-	-	-	+	170	30	56	33

Id.	(%) of formed fruits/covered buds	(%) of fruits collected/fruits formed	Presence (+) / absence (-)				Plant height (cm)	Stem circumference (cm)	Height at first fruit (cm)	Fruits per plant (no.)
			Virus	Mites	Chicharrite	Other insects				
HP10	44.4	25	-	+	-	+	195	29	40	40
HP11	60	16.7	-	+	-	-	200	35	43	28
HP13	57.1	25	+	-	-	+	171	36	60	29
HP14	44.4	25	-	-	-	+	222	33	55	33
HT2	37.5	33.3	+	+	-	+	182	34	45	38
HT7	66.7	25	-	+	-	-	169	30	55	37

In the same Table 2, we can also see the phytosanitary status record (presence/absence) of three main phytosanitary problems in the region, and concentration of other less persistent pests (whitefly, aphids), in this respect, leafhopper was not detected in the orchards, at least in the sampling period. Regarding height of the plant and stem circumference, they showed characteristic values of the Maradol type, the height to the first fruit and the number of fruits per plant are acceptable for their integration of these materials in an improvement process (Table 2).

It is important to note that the papaya industry faces two main problems, diseases and sex differentiation in seedling stage (Karambu *et al*., 2018). It should be noted that *Carica papaya* is propagated by seeds, with this heterogeneity of the plants (Bhattacharya and Khuspe, 2001). In addition, in Mexico the main variety of cultivated papaya is Maradol (Santamaría *et al*., 2009). So the selection of plants is the first work of great importance, it means a good start to improve the crop.

The initial process is based on locating a plantation or uniform plants, good yield, health, vigor and growth characteristics such as uniformity in size and shape of fruits, uniformity of production, beginning of flowering of low height and predominance of sex hermaphrodite, in addition, the plants should not have deformed fruits. All these characteristics must be suitable, since they are inheritable (Díaz, 2002). Therefore, in the present study the methodology used pursues the fundamental principles to have an appropriate genetic base to choose promising materials.

Regarding the characterization of the fruits, the results are presented in Table 3, the weight of the fruit was tolerable, oscillating between 0.9 to 1.36 kg and this in turn was reflected in the size of fruit and width of pulp whose tendency was similar. The values of soluble solids and pulp hardness reveal adequate sweetness and firmness, respectively. The yields per plant were variable; however, with the minimum registered yield of the HP13 orchard, at a traditional reserved density of 2 000 plants ha^{-1}, it is possible to exceed 50 t ha^{-1} (Table 3).

Table 3. Characterization of collected fruits and estimated yield of outstanding papaya plants.

Id.	Circumference of fruit		Weight of fruit (kg)	Pulp width (cm)	Soluble solids (ºBrix)	Pulp firmness (kg cm^{-2})	Estimated yield/plant (kg)
	Polar (cm)	Equatorial (cm)					
HP3	58	44	1.146	2.7	12	2.1	38.96
HP4	60	39	1.125	3	14	2	33.75
HP5	51	46	1.23	2.8	13	2.1	33.21
HP6	59	41	1.36	2.7	11	1.9	43.52
HP7	49	38	0.975	2.2	15	2.2	29.25
HP8	50	32	1.111	2.5	12	2.1	36.66
HP10	46	36	1.001	2.3	13	1.9	40.04
HP11	47	38	1.15	2.4	11	2	32.2
HP13	44	37	0.98	2.2	15	2.1	28.42
HP14	50	39	1.125	2.4	13	2.2	37.12
HT2	49	38	0.9	2.5	12	1.9	32.2
HT7	54	40	1.07	2.1	11	2.2	39.59

On the other hand, the calculated statistical values of the registered variables are shown in Table 4.

Table 4. Statistical parameters of the variables registered in outstanding papaya plants.

Statistical	AP (cm)	CT (cm)	APF (cm)	FP (no.)	CPF (cm)	CEF (cm)	PF (kg)	AP (cm)	SS (ºBrix)	FP (kg cm^{-2})	REP (kg)
Mean	183.16	32.5	48.25	32.58	51.41	39	1.09	2.48	12.66	2.05	35.41
Standard deviation	17.6	2.61	7.17	4.1	5.23	3.61	0.12	0.27	1.43	0.11	4.63
Standard error	5.08	0.75	2.07	1.18	1.5	1.04	0.03	0.07	0.41	0.03	1.33
Minimum	159	29	37	27	44	32	0.9	2.1	11	1.9	28.42
Maximum	222	36	60	40	60	46	1.36	3	15	2.2	43.52
CV (%)	9.61	8.03	14.86	12.58	10.17	9.27	11.36	10.97	11.33	5.65	13.1
Variance	309.96	6.81	51.47	16.81	27.35	13.09	0.01	0.07	2.06	0.01	21.52
95% confidence interval	9.96	1.47	4.05	2.31	2.95	2.04	0.07	0.15	0.81	0.06	2.62
99% confidence interval	13.11	1.94	5.34	3.05	3.89	2.69	0.09	0.2	1.06	0.08	3.45

AP= plant height; CT= stem circumference; APF= height at first fruit; FP= fruits per plant; CPF= polar circumference of fruit; CEF= equatorial circumference of fruit; PF= fruit weight; AP= pulp width; SS= soluble solids; FP= pulp firmness and REP= estimated yield per plant.

Both the qualitative and quantitative characteristics of flowers, leaves, seeds, plants and mainly fruits, are important parameters to evaluate in the selection of materials (Oliveira de *et al*., 2012). Particularly, °Brix higher than 12, red pulp color, fruit size and adequate fruit shape and non-deformed elongate, are minimum fruit quality requirements for obtaining seed (Stice *et al*., 2016).

Also, the color of the peel is the most used characteristic to evaluate the state of maturation of the fruits of papaya (Santamaría *et al*., 2009) and this supports a visual criterion in the election of the fruits.

Regarding the behavior of the germination, in the period of soaking there was a low percentage of seedless, even in some orchards there was no. As for the general germination, it was higher than 80% (Figure 1).

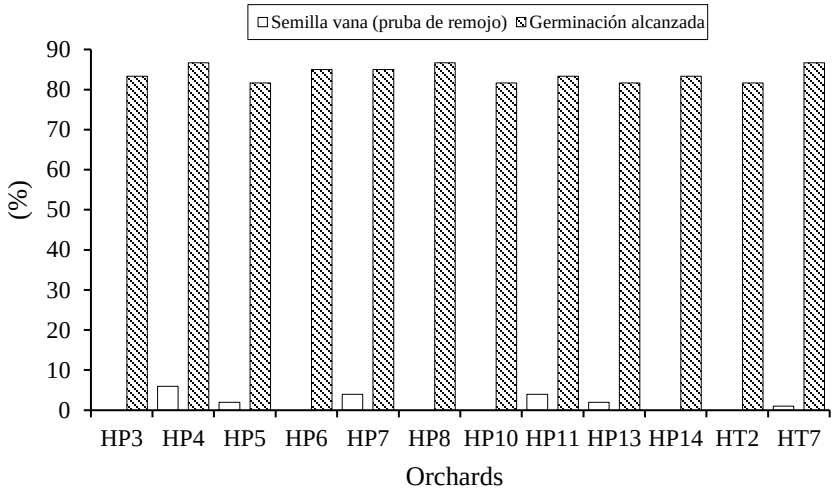

Figure 1. Vain seed and germination achieved in outstanding papaya plants.

While the germination response period was between 9 and 14 days; however, the highest germination was recorded at 12 days (Figure 2).

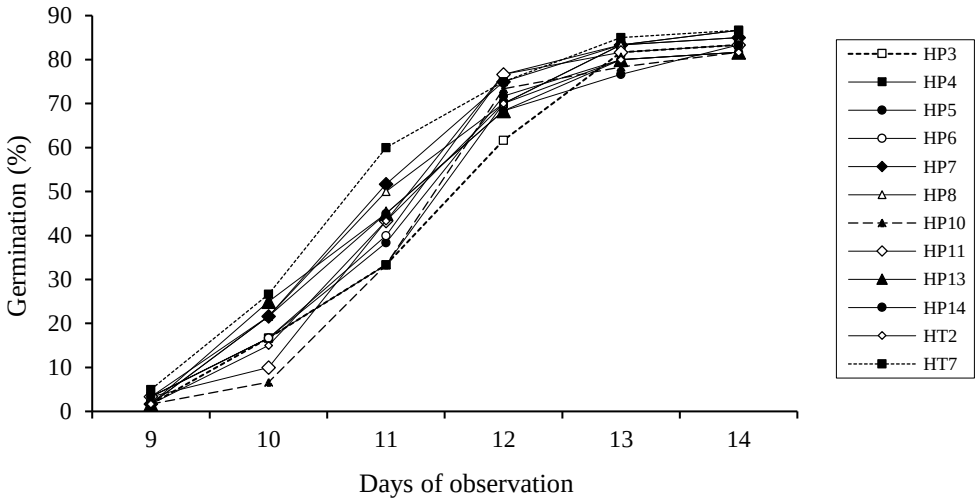

Figure 2. Variation of germination over time in outstanding papaya plants.

As already indicated, the agronomic characteristics of tolerance or resistance to diseases are the main desirable aspects of breeding programs, based on an extended genetic base in order to satisfy the market (Silva *et al*., 2007) and in that identification, the analysis of growth allows to differentiate characteristics of initial growth that make possible the increase of the yield in adult

stage and favor the works of improvement in search of more productive genotypes, with this, it is possible to explain differences in the growth of genetic origin or due to environmental modifications (Rodríguez *et al*., 2015).

Given that the genetic variability in commercial populations, allows to consider the exploitation of the papaya crop taken as a basis for the development of improved cultivars. In this subject, few reports exist on commercial populations (Pares *et al*., 2002; Aikpokpodion, 2012). The papaya is based on a narrow genetic base and few varieties and/or commercial hybrids for sowing are available and that do not meet the demands of national and international markets (Filho *et al*., 2007), since the price of the seed of imported hybrid papaya is high, this encourages producers to select generations F2 to F4 in continuous plantations, even when there is a risk of loss of vigor and segregation in the shape of the fruit (Marin *et al*., 2006).

So the collection of seeds, derived from the protection of flower buds, is a common practice (Stice *et al*., 2016), unlike the hybrids that are generated by two consanguineous parents and their development is slow, so that this process is complicated by the elimination of male parts of the flower (Chan, 2014). Therefore, exploratory studies in commercial environments are important to identify promising materials for the implementation of a multiplication and distribution strategy.

Conclusions

In 12 orchards, selected papaya plants were identified based on outstanding characteristics and adapted to the production area of Michoacán. The quality fruits collected varied among selected plants, since during the process from the selection of flower buds to the formation of fruits there is a loss by natural condition of more than 50%. Of the four phytosanitary problems of economic importance in the region, the leafhopper was not registered in the orchards registered.

The registered values of the morphological and fruit variables correspond to the characteristics of the Maradol variety. The germination of the seed was higher than 80% and occurred in greater proportion at 12 days.

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