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SEARCH FOR NOTABLE TRAITS IN PAPAYAS FROM COMMERCIAL ORCHARDS FOR LINES CONSERVATION IN MICHOACAN, MEXICO

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Abstract: Currently there are few varieties of papaya in Mexico and the dominant variety is 'Maradol', which over time has been vulnerable to phytosanitary problems. However, for the development of varieties and seed production, the control of plant pollination necessarily intervenes because it is an open-pollinated species. Therefore, the development of papaya varieties with better agronomic traits, where the greatest number of characteristics are concentrated in commercial genotypes, is a challenge, which is why it is necessary to rescue genetic material adapted to the regions of interest, in order to have a diverse genetic source. Based on the above, the objective was to select papaya plants with outstanding characteristics in commercial orchards. Through explorations, hermaphroditic Maradol papaya plants with outstanding characteristics were identified and characterized. Flower buds were selected in the plants and were covered to induce self-pollination. The formed fruits were collected and the seeds were obtained. Plant and fruit morphological variables, health and germination were recorded. Outstanding plants were presented in 13 commercial orchards. The characterization of the progress in the development of floral bud to fruit was varied, so the number of fruits formed was reduced in relation to the initially covered buds, as well as the number of fruits collected in relation to the fruits formed was reduced. The presence of viruses, mites and other insects was recorded in most of the registered orchards. It is concluded that papaya selected based on outstanding characteristics and adapted to the producing region of Michoacán Mexico were identified.

Keywords: *Carica papaya*, 'Maradol' genotype, hermaphrodite, plant sexing.

INTRODUCTION

Of the fruit trees of economic importance, *Carica papaya* L. is widespread in the tropical and subtropical regions of Mexico, due to the environmental conditions that the country presents, derived from its privileged geographical position that favors it. This fruit species is fast growing and has high physiological activity. For its fruit, it is appreciated for its excellent quality, whose annual per capita consumption is 6.4 kg (SIAP, 2017).

Papaya cultivation in Mexico, between 2010 and 2022, the established area grew 21.63%, going from 16,261 to 20,750 ha; Total production increased by 43.16%, going from 648,235 to 1,140,501 t; and the yield per hectare increased 19.70%, going from 46.49 to 57.90 t ha^{-1}. The harvested area in 2022 in Mexico was 19,698 hectares, whose participating states include Veracruz, Colima, Michoacan, Oaxaca, Chiapas and Guerrero. However, in yield per hectare, Oaxaca reached first place with 112.34 t ha^{-1} and Veracruz with 32.85 t ha^{-1}, being the state with the lowest yield per hectare. Particularly, the record of the state of Michoacán has been variable in the last 13 years, since the average cultivated area was 2,795 (±687) ha, the total yield was 71,832 (±28,677) t and the yield per hectare was of 33.48 (±2.53) t ha^{-1} (SIAP-SADER, 2023).

Due to market demand, in the producing regions the Maradol variety is the dominant one (SIAP, 2017), in its different levels of fruit quality, since the type of seed used varies from the original F1 to descendant selections F2 to F5. The above leads to genotypic and phenotypic 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).

Studies indicated by FEITÓ AND PORTAL (2013) indicate that the papaya

agri-food chain faces difficulties associated with the low capacity for innovation and development; in addition, it depends on the production of seeds from the foreign market and almost all of its production depends on only from the Maradol variety. However, the reality is that *Carica papaya* is a very complex species from a physiological point of view, and this complexity is reflected in fruit production, so it is important to understand the different floral aspects (ALVAREZ *et al*., 2018). Therefore, the selection of parents and controlled pollination to obtain seeds are important aspects, where crossings must be carried out between hermaphrodite plants or promote self-pollination of these to obtain 66% of seeds that will give rise to hermaphrodite plants (RAM, 2005).

When selecting plants for seed multiplication purposes, the requirements must be met to guarantee their origin and quality based on the following characteristics: they must be vigorous, the phenotype must correspond to the desired variety, free of pests and diseases or varieties that show tolerance, minimum production of carpeloid fruits on a hermaphrodite plant during winter, female or hermaphrodite fruits, present characteristics that allow determining that it is an optimal production, be located at a low altitude, must obtain a minimum production of sterile female flowers at the end of summer and at the beginning of autumn or during dry periods, be uniform, both in size and shape of the fruit (SNICS-SAGARPA, 2014).

Framed in the philosophy of intensive horticulture, the strategy is based on achieving higher yields per cultivated area with the purpose of increasing levels of productivity and competitiveness. Therefore, it is necessary to rescue genetic material that can be used in the improvement of papaya for seed production, but that is also adapted to the region of interest (SNITT-SAGARPA, 2016). Based on the above, the objective was to select papaya plants in commercial orchards with outstanding characteristics and adapted to the papaya producing area of Michoacán, Mexico.

MATERIALS AND METHODS

Through field explorations in commercial papaya plots, located in the production area of Michoacan, Mexico, specifically in the Apatzingan Valley, during 2022 and 2023, papaya plants of the Maradol type were identified. The characteristics sought in these plants were based on them being plants with a healthy visual appearance and excellent vigor, of a hermaphrodite 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 at anthesis or close to the floral opening, and in order to ensure that there was no cross-pollination, the buds were covered with a waxed glassine paper bag, and each bud was a label was placed with respective information for later identification. The process of developing the buds until reaching physiological maturity of the fruit took approximately 5 months. After that date, as the fruits matured, they were collected for seed extraction and conditioning through washing and were preserved for the next germination study, which was based on soaking the seed in water for three days, and eliminating the floating seed, considered as vain seeds. The rescued seed was placed in damp flannels and kept at room temperature at 27(±3) ºC. In addition, the level of health of the plants was recorded, through visual exploration of the adjacent plants with respect to the outstanding plants, the presence or absence of insect-pests was determined, this in order to foresee some degree of tolerance or resistance.

The variables recorded were: characterization of the sites using specialized

equipment and literature; percentage of formed fruits and fruits collected on the initially covered buds; presence and/or absence of viruses and main papaya pests; plant height, first fruit and stem circumference, a measuring tape was used; and the number of fruits per plant at harvest stage was taken. The polar and equatorial circumference of the collected fruits was recorded with a measuring tape; the fruit shape index, using the formula polar circumference divided by equatorial circumference; the weight of fruit with a digital scale; pulp width with a graduated ruler; soluble solids, with refractometer; pulp firmness, with manual penetrometer; and performance estimation per plant. In relation to germination, knowing the initial seed number and by difference, the empty seed was recorded and later the germinated seed, and the period in which it occurred.

The recorded data were analyzed with descriptive statistics, while the germination test was percentage. The statistical package used was PAST 3.2 (HAMMER, 2018).

RESULTS

In four municipalities of the Apatzingan Valley, Michoacan, Mexico, 13 commercial papaya orchards were explored. The geographic location and altitude followed a common pattern; in turn, the surfaces and genotypes of the orchards were variable. Despite this, outstanding plants were identified, since they presented this type of plants in locations that corresponded to the municipalities of Apatzingan, Mujica, Paracuaro and Tepalcatepec, and information on the variables considered was recorded on these. The numerical values of buttons and fruits by orchards are also shown (Table 1).

In relation to the process in the development of flower buds to formed fruits of papaya quality, the percentage values achieved are shown in table 2. As can be seen, during development the amount of fruits formed in relation to the covered buds was reduced, as well as, reduced the amount of fruits collected in relation to the fruits formed, due to factors of a diverse nature that influenced the process, with this, the quality fruits in the orchards presented percentages greater than 50% of fruits collected.

For its part, the record of the phytosanitary status of three main problems in the region, which were viruses, mites and other less persistent insects (whiteflies and aphids). Regarding plant height and stem circumference, they presented characteristic values of the Maradol type, the height at the first fruit and the number of fruits per plant are acceptable for the integration of these materials in a breeding process (Table 2).

Regarding the characterization of the fruits, the results are presented in table 3, the weight of the fruit was tolerable, ranging between 1.12 to 1.38 kg and this in turn was reflected in the fruit size, fruit shape index and pulp width whose trend 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 yield recorded from orchard six, at a traditional reserve density of 2,000 plants per ha, it is possible to exceed 50 t ha^{-1} (table 3), thereby exceeding the national average.

Regarding the sample statistics, derived from the calculated values of the variables recorded in outstanding papaya plants, they are shown in table 4.

Regarding germination behavior, in the soaking period there was a low percentage of wasted seeds. Regarding general germination, it was greater than 80% (Figure 1). While the germination response period was between 9 and 14 days, however, the highest germination was recorded at 12 days (Figure 2).

ID	Municipality	Location	North Latitude	West Longitude	Altitude (m)	Surface (Ha)	Genotype	Chosen plants (No.)	Protected buds (No.)	Fruits formed (No.)	Quality fruits (No.)	
	H1	Apatzingán	Puerta de Alambre	19°03′33′	102°24′51′′	314	6	Maradol	3	7	5	3
	H2	Mujica	Nueva Italia	18°55′32′	102°09′48′′	421	8	Maradol	2	6	3	2
	H3	Mujica	Nueva Italia "Aguacate"	18°58′53′	102°10′04′′	378	8	Mulata	3	10	6	4
	H4	Mujica	Ceñidor "canal"	18°58′44′	102°10′52′′	359	8	Maradol	3	8	5	3
	H5	Mujica	Ceñidor "Carretera"	18°59′34′	102°11′35′′	327	10	Maradol	3	8	4	2
	H6	Mujica	Ceñidor "Carretera"	18°57′27′	102°09′33′′	364	6	Maradol	3	6	4	2
	H7	Paracuaro	Ciudad Morelos	19°00′15′	102°17′20′′	328	6	Maradol	1	3	2	1
	H8	Paracuaro	Antúnez	18°57′40′	102°13′14′′	324	8	Maradol	2	8	5	4
	H9	Paracuaro	Antúnez "La perla"	18°56′09′	102°13′35′′	319	4	Maradol	3	9	5	3
	H10	Paracuaro	Las Yeguas	19°00′42′′	102°14′52′′	312	9	Maradol	2	6	4	3
	H11	Tepalcatepec	Cholula	19°07′54′	102°50′34′′	370	7	Maradol	3	6	5	3
	H12	Tepalcatepec	Atascadero	19°08′13′	102°51′58′′	342	10	Maradol	3	7	5	4
	H13	Tepalcatepec	Calderitas	19°10′22′	102°50′25′′	376	9	Mulata	1	4	3	3

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

ID.	% of fruits formed / buds covered	% of fruits collected / fruits formed	Presence (+) / absence (-)				Plant height (cm)	Stem circumference (cm)	Height to first fruit (cm)	Fruits per plant (No.)
			Viruses	Mites	Leafhopper	Other insects				
H1	71.4	60.0	+	-	-	+	203	34	53	31
H2	50.0	66.7	+	+	+	+	224	40	44	34
H3	60.0	66.7	-	-	+	+	230	38	51	36
H4	62.5	60.0	+	+	+	-	198	46	48	28
H5	50.0	50.0	+	-	+	+	251	41	42	30
H6	66.7	50.0	+	+	+	+	229	39	49	23
H7	66.7	50.0	+	+	+	+	204	35	58	28

H8	62.5	80.0	-	-	-	-	243	40	53	35
H9	55.6	60.0	+	-	-	+	198	41	60	30
H10	66.7	75.0	+	+	+	+	238	37	51	30
H11	83.3	60.0	+	+	+	+	223	34	44	29
H12	71.4	80.0	+	+	+	+	210	38	42	33
H13	75.0	100.0	+	+	-	+	235	41	55	39

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

Statistical	PH (cm)	ST (cm)	HFF (cm)	FP (No.)	PFC (cm)	EFC (cm)	FSI (cm)	FW (kg)	PW (cm)	SS (ºBrix)	PF (kg cm^{-2})	EYP (kg)	G (%)
Men	222	38.76	50	31.23	53.53	42.23	1.26	1.25	2.8	12.38	2.17	39.06	85.27
Standard deviation	17.80	3.34	5.87	4.14	6.09	3.05	0.09	0.09	0.22	0.65	0.05	5.32	2.23
Standard error	4.93	0.92	1.62	1.14	1.68	0.84	0.02	0.02	0.06	0.18	0.01	1.47	0.62
Minimum	198	34	42	23	41	36	1.08	1.12	2.5	11	2.1	26.22	80.00
Maximum	251	46	60	39	60	48	1.38	1.39	3.1	13	2.3	46.44	88.33
CV (%)	8.02	8.62	11.74	13.27	11.37	7.24	7.50	7.90	8.11	5.25	2.75	13.64	2.62
Variance	317.16	11.19	34.50	17.19	37.10	9.35	0.01	0.01	0.05	0.42	0.01	28.40	5.01
Confidence interval 95%	9.68	1.82	3.19	2.25	3.31	1.66	0.04	0.05	0.12	0.35	0.03	2.90	1.21
Confidence interval 99%	12.74	2.39	4.20	2.97	4.36	2.19	0.06	0.07	0.16	0.47	0.04	3.81	1.60

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

PH=Plant height; ST= Stem circumference; HFF=Height to first fruit; FP=Fruits per plant; PFC= Polar Fruit circumference; EFC=Equatorial fruit circumference; FSI=Fruit shape index FW=Fruit weight; PW=Pulp width; SS=soluble solids; PF=pulp firmness; EYP=Estimated yield per plant and G=Germination.

ID.	Circumference of fruit		Fruit shape index	Weight of fruit (kg)	Pulp width (cm)	Soluble solids (°Brix)	Pulp firmness (kg·cm^{-2})	Estimated yield/plant (kg)
	polar (cm)	equatorial (cm)						
H1	55	43	1.28	1.39	2.9	12	2.2	43.09
H2	60	44	1.36	1.12	3.1	12	2.1	38.08
H3	57	44	1.30	1.29	2.9	12	2.2	46.44
H4	58	43	1.35	1.29	3.1	13	2.2	36.12
H5	55	42	1.31	1.32	2.5	13	2.1	39.6
H6	47	36	1.31	1.14	2.8	13	2.2	26.22
H7	59	48	1.23	1.39	2.5	13	2.2	38.92
H8	41	38	1.08	1.32	2.7	12	2.3	46.2
H9	58	42	1.38	1.26	2.9	13	2.1	37.8
H10	44	39	1.13	1.15	3.1	12	2.2	34.5
H11	57	43	1.33	1.32	2.6	13	2.2	38.28
H12	55	43	1.28	1.18	2.5	12	2.1	38.94
H13	50	44	1.14	1.12	2.8	11	2.2	43.68

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

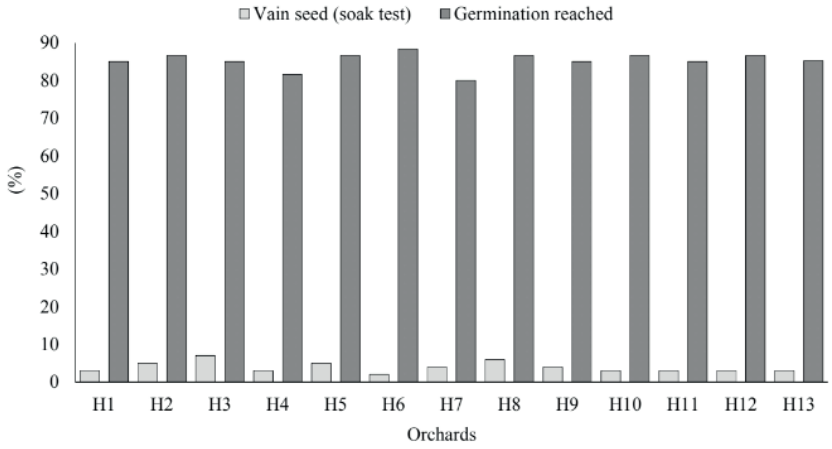

Figure 1. Germination behavior of papaya seeds, obtained from fruits of selected plants.

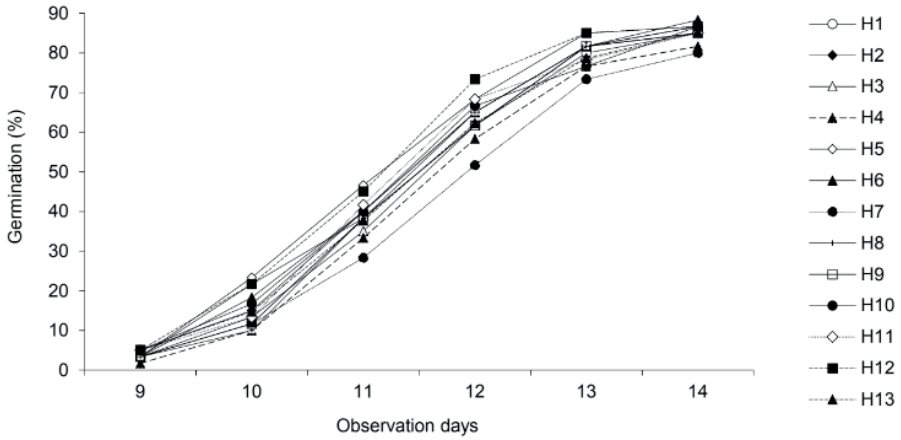

Figure 2. Germination progress of papaya seed obtained from fruits of selected plants, in a temporal period.

DISCUSSION

It is important to note that the papaya industry faces two main problems, diseases and sex differentiation in the seedling stage (KARAMBU *et al*., 2018). It should be noted that *Carica papaya* is propagated by seeds, resulting in plant heterogeneity (BHATTACHARYA AND KHUSPE, 2000). Furthermore, in Mexico the main cultivated papaya variety is Maradol (SANTAMARIA *et al*., 2009). Therefore, the selection of plants is the first task of great importance, as it means a good start to improving the crop. The initial process is based on locating a uniform plantation or plants, with good performance, health, vigor and growth characteristics such as uniformity in size and shape of fruits, uniformity of production, beginning of flowering at a low height and with predominance of the sex hermaphrodite, in addition, the plants should not have deformed fruits. All these characteristics must be ideal, since they are heritable (DÍAZ, 2002). Therefore, in the present study, the methodology used pursues the fundamental principles to have an appropriate genetic basis to choose promising materials.

Both the qualitative and quantitative characteristics of the flower, leaves, seed, plant and mainly fruits, are important parameters to evaluate in the selection of materials (OLIVEIRA DE *et al*., 2012). Particularly, °Brix greater than 12, red pulp color, fruit size and appropriate, elongated, non-deformed fruit shape are minimum fruit quality requirements for obtaining seeds (STICE *et al*., 2016). In addition, the color of the peel is the most used characteristic to evaluate the ripening state of papaya fruits (SANTAMARÍA *et al*., 2009), and this supports a visual criterion in the choice of fruits.

As already noted, the agronomic characteristics of tolerance or resistance to diseases are the main aspects desirable for breeding programs, based on an expanded genetic base in order to satisfy the market (SILVA *et al*., 2007), and in With this identification, growth analysis allows us to differentiate initial growth characteristics that enable increased performance in the adult stage and favor breeding work in search of more productive genotypes. With this, it is possible to explain differences in growth of genetic origin or due to to environmental modifications (RODRÍGUEZ *et al*., 2015). Given that the genetic variability in commercial populations allows considering the exploitation of papaya cultivation taken as a basis for the development of improved cultivars.

On this topic, few reports exist on commercial populations (AIKPOKPODION, 2012; PARES *et al*., 2002). Papaya is based on a narrow genetic base and few commercial varieties and/or hybrids for planting are available and do not satisfy the demands of national and international markets (FILHO *et al*., 2007), given that the price of papaya seed imported hybrid papaya is high, this encourages producers to select F2 to F4 generations in continuous plantations, even though there is a risk of loss of vigor and segregation in the shape of the fruit (MARIN *et al*., 2006), so the Seed collection, derived from the protection of flower buds, is a common practice (STICE *et al*., 2016), unlike hybrids that are generated by two inbred parents and their development is slow, so this process is complicated by the elimination of the 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

Thirteen orchards were identified with papaya plants selected based on outstanding characteristics and adapted to the production area of Michoacan. The quality fruits collected varied between selected plants, since during the process from choosing flower buds to fruit formation there is a loss due to natural conditions of more than 50%. The recorded values of the morphological and fruit variables correspond to the characteristics of the Maradol variety. Seed germination was greater than 80% and occurred in a greater proportion after 12 days.

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