Chapter

Grafting in Horticultural Crop Species: Effective Pest and Disease Management Technique with Potential in Michoacan, Mexico

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Abstract

The grafting technique is an effective alternative in crop management, specifically for the management of pests and soil pathogens; therefore, it has been recognized in all agricultural areas, which makes the a horticultural production technique more respectful with the environment. In general, this technique has been widely used in fruit growing; however, it has also been of great importance in the production of vegetables worldwide. In vegetables, the same principles applied to the grafting of fruit trees are followed, as well as specific requirements, such as controlled climatic conditions and greater care. In Michoacan, Mexico, by the phytosanitary condition in cucurbits, Solanaceae, and Caricaceae, the use of rootstocks with specific resistance characteristics offers an option for the recovery of soils, without repercussion in the environment. Although in Mexico this technique has been little exploited, in Michoacan, it is innovative in crops of Solanaceae, Cucurbitaceae, and Caricaceae. The use of grafted plants helps to improve the conditions of the crop, but also, if this technique is included in a program of integrated management of pests and diseases, it ensures the success of the production.

Keywords: approach grafting, cleft grafting, grafting, papaya, rootstock, tomato, watermelon

1. Introduction

In theory, the graft is the union of two or more pieces of living tissue, which once joined together develops as a single plant [1]. This combination of desirable characteristics consists of the removal of buds of a plant that is called graft and the root that is provided by a plant that is called rootstock [2]. The production of plant grafts has been widely expanded for fruit tree and vegetable crops, and different studies have shown that the success of the crop depends on the rootstock selected when compared with non-grafted plants [3].

In some countries, the grafting technique has been integrated into the scheme of agricultural work as an effective alternative in the management of the crops. Therefore, it has been recognized in all agricultural areas, which makes it a technique of horticultural production more respectful with the environment [4]. With this technique, the tolerance of the root system of the rootstock and the favorable productive characters of a susceptible variety are used. In vegetables the same principles applied to the grafting of fruit trees are followed, in addition to controlled environment requirements and greater post-graft care. So, the use of similar rootstocks strengthens and gives vigor to plants, therefore keeping nematodes and diseases controlled for longer than a plant that has not been grafted [5, 6].

Although there is evidence that the art of grafting was known to the Chinese from 1000 years ago before Christ [1], the grafting technique has its beginnings in the 1920s in watermelon grafted on pumpkin (*Cucurbita moschata* Duch) as rootstock, to confer resistance to wilt caused by *Fusarium*. Currently this technology is practiced successfully in Cucurbitaceae and Solanaceae in Asia and in Mediterranean countries [7]. The use of the grafting technique has been aimed at improving crops such as fruit trees and vegetables, to get their development under varied agronomic conditions [8]. It improves the resistance of crops to biotic and abiotic stresses such as salinity [9], drought tolerance [10], and nutrient deficiency [11], and this technique can be an important tool to improve fruit quality.

In Mexico, this technique is recent; however, the advantages of using it as a substitute for fumigants can counteract the main phytosanitary problems that limit the production of crops. Otherwise, in the State of Michoacan, like other states of the Mexico, the various contrasts give rise to different production systems, which favor the establishment of different crops. Despite being a predominantly agricultural territory, it has been severely affected by the production system of the monoculture type and the indiscriminate use of agrochemicals, which has caused resistance of pests and pathogens difficult to control by conventional systems. Therefore, among the management alternatives, we can see the use of the graft. Given the phytosanitary situation presented by Cucurbitaceae and Solanaceae in the State of Michoacan, the use of rootstocks with specific resistance characteristics offers an option for the recovery of soils, without repercussion in the environment. As mentioned, in our country this technique has not been fully exploited, in the State of Michoacan, it is new and innovative in the cultivations of Solanaceae, Cucurbitaceae, and Caricaceae.

2. Productive importance of tomato, watermelon, and papaya with graft potential

Mexico is located in a privileged geographic position, which favors the environmental conditions for the development of different crops in open field, and where the conditions are restrictive, crops are grown in greenhouses. Among the crops of economic importance and with potential of graft are tomato (*Solanum lycopersicum* L.), which is the second most important horticultural crop after potato; watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai], being an herbaceous creeping plant with 6 m in length in its branches and a highly valued product for its quality of freshness, mainly in hot seasons, and palatability in any season of the year; and papaya (*Carica papaya* L.), of the fast growing fruit species that is widespread in tropical and subtropical regions. The annual consumption *per capita* in these species is tomato, 14.3 kg; watermelon, 3.7 kg; and papaya, 6.4 kg [12].

According to SIAP-SAGARPA [13], in the last years at national level, the cultivated area has presented variable trends in tomato and watermelon, with greater amount of hectares cultivated in the year 2010, and as the years pass until the year 2017, they were reduced in 11% and 14%, respectively. However, this trend differs in the total production and the yield per hectare, since percentage of the year 2010 to the year 2017 for the tomato increased 33% and 22%, respectively, and for the

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Year	Tomato			Watermelon			Papaya		
	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)
2017	48,394	3,055,861	64.832	42,105	1,296,767	32.015	19,114	964,702	57.82
2016	48,840	2,769,611	59.336	39,903	1,129,219	30.544	19,442	957,415	56.895
2015	49,530	2,570,284	56.077	36,197	1,003,213	28.71	17,530	879,363	55.426
2014	50,850	2,320,109	48.777	35,511	955,186	28.092	16,071	840,497	57.445
2013	44,504	2,052,126	49.101	37,482	937,378	26.086	15,952	734,522	51.542
2012	55,504	2,459,874	47.102	38,288	1,011,667	27.307	16,725	680,204	49.241
2011	56,025	1,670,454	41.758	47,387	1,002,506	25.006	17,142	646,002	44.909
2010	54,238	2,058,424	42.104	48,667	1,016,215	23.375	16,261	648,235	46.49

Table 1.
The trend in tomato, watermelon, and papaya areas of cultivation, total production, and yield in Mexico country from 2010 to 2017 [13].

Year	State of Michoacan								
	Tomato			Watermelon			Papaya		
	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)	Cultivated area (ha)	Total production (t)	Yield ($t{\cdot}ha^{-1}$)
2017	5866	211,100	36.382	990	32,337	32.680	3326	79,207	33.442
2016	6826	178,252	29.170	679	20,769	31.421	3510	70,198	32.849
2015	7845	178,931	26.204	888	21,765	24.511	2424	51,714	31.476
2014	5894	117,710	23.568	507	12,128	23.922	2128	48,605	35.094
2013	3905	73,253	24.371	676	16,500	24.427	1944	35,401	26.921
2012	5017	150,690	35.624	604	14,836	24.563	2031	43,935	33.009
2011	4768	128,367	29.013	618	15,189	24.677	2063	45,002	32.076
2010	5186	79,291	24.469	696	14,918	25.836	1998	47,947	32.999

Table 2.
The trend in tomato, watermelon, and papaya areas of cultivation, production total, and yield in the state of Michoacan, from 2010 to 2017 [13].

vvsituation for papaya, the cultivated area, the total production, and the yield per hectare, the trend always has been increasing from 2010 to 2017 (**Table 1**).

The record of the last years in the State of Michoacan has been unstable in the harvested area, total production, and yield in the three crops. However, from 2010 to 2017, the trend has been mostly upward (**Table 2**).

For its part, the various activities related to the production of tomato, watermelon, and papaya in the State of Michoacan are of great importance because they generate direct and indirect jobs, as well as being the sustenance of many families. Given the economic and social importance of these crops, their production is necessary under efficient and sustainable systems. The choice of genotypes, plantation density, phytosanitary management, and the incorporation of the grafting technique are fundamental practices to achieve higher yields and improve the quality of fruits. Nevertheless, ignorance of the correct application negatively impacts the production.

3. Current situation of potentially graft species

Tomato is one of the crops with the greatest phytosanitary problems [14], which have represented a serious problem due to the use of insecticides. This causes the death or many natural parasites of insect pests and creates genetic resistance to insecticides [15, 16]. Diseases are another limiting factor in the production of tomato [17]. Viral pathogens are disseminated by insect vectors, fungal and bacterial. Also, pathogens disseminated by seed, irrigation water and wind mean a potential danger in extensive areas of monoculture.

To achieve health in crops, measures of exclusion, eradication, and protection are used, in the context of an integrated control and use of resistant cultivars. In tomato, the theory on plant resistance has served as the basis for the development of varieties resistant to pathogens and insects, whose main source of resistance is found in wild plants [18–20]. Among the strategies to induce resistance, the conventional improvement by hybridization [21] and, another perhaps less used, the grafting technique can be distinguished [22].

Watermelon is cultivated during two cycles per year (autumn-winter and spring-summer), in irrigation and temporary. Wilt caused by *Fusarium* is considered a disease that gradually deteriorates the vigor of watermelon [23]. Also, root-knot nematodes are associated with watermelon [24]. Moreover, due to influence of agroclimatic factors and crop management, the production systems are varied [25], so the use of arbuscular mycorrhizae [26] and use of adapted genetic material, diploid or triploid hybrids [27], all contribute to obtain better yields.

Therefore, it is feasible that watermelon with management practices such as mulching, technified irrigation, and sowing methods different from the conventional one would considerably improve the productive system and competitiveness [28]. By its nature, watermelon genotypes have a high productive potential, which leads to determine their agronomic behavior to the environmental conditions of each region. Grafting technique is recognized in the agricultural ambit, and effective without negative impact on the environment, this condition is revalued with the imminent prohibition of the use of methyl bromide and its nonpolluting effect [4].

Papaya, in some stages within the production process, presents various kinds of problems. There is evidence that over time when the monocultures are continuously established, they bring with them the proliferation and resistance of pests and diseases, in which its management is difficult and has influences in the yield; also this crop requires answers oriented to the high productivity, where the densities and the nutrition play an important role. The alternatives to address the phytosanitary and physiological problems revolve around the improvement of the crop, and this can occur through the hybridization and crossings of materials, also selection of seeds, genetic engineering by including resistance genes, and in vitro propagation, all of them with the complexity of the processes and the response times. Particularly, tissue culture techniques such as micropropagation [29] both for organogenesis [30] and somatic embryogenesis have been considered for the in vitro propagation of this species; however, as biotechnological methods are until the present more expensive in relation to the use of seed, it is limited, only to hybrid genotypes that it justifies [31].

In papaya by its polygamous character, with three basic types of flowers, staminated, pistillate, and hermaphroditic, the typical propagation by seed is hindered by variability in the expression of the sexual characters and subsequent shape of the fruits. Therefore, the asexual propagation through the grafting technique would improve the papaya industry [32], since through the graft it is possible to maintain the original characteristics of the mother plants, in addition, to increase the yield, reduce height, and improve fruiting; some studies support it [33–35].

4. Grafting use in horticultural crops

In herbaceous plants, the union between the rootstock and graft is carried out by the formation of a callus of parenchymatous tissue, a structure that is differentiated to cambium tissue, which will give rise to the xylem and phloem, with which the union between vascular bundles of both individuals is restored.

It is worth mentioning that the fumigation of the soil with methyl bromide to control some soil pathogens was until recently considered one of the main factors for the success of the production of Cucurbitaceae and Solanaceae. However, the banning of methyl bromide and the lack of tolerant or resistant cultivars to biotic stress have increased the interest by the use of the grafting of vegetables [4, 36].

Some cases are mentioned on the use of grafts in the induction of resistance to pests and diseases. From the beginning, the grafting technique was used for the management of soil pathogens; currently it includes Cucurbitaceae and Solanaceae, in species of *Citrullus lanatus*, *Cucumis melo*, *Cucumis sativus*, *Solanum lycopersicum*, *Capsicum annum*, and *Solanum melongena* [37].

Cucurbitaceae are grafted on pumpkin rootstocks (*Cucurbita moschata* Duchesne and *Cucurbita maxima* Schrad) to confer resistance against soil pathogens [38]; *Phytophthora capsici* is one of the main pathogens of global importance in *C. annuum*; likewise, its management has been achieved by grafting [39], in *S. melongena* to control of *F. oxysporum* f. sp. *melongenae* [40].

On the other hand, environmental stress represents the condition with the greatest limitation for horticultural productivity and use of plants. The temperature causes economic losses of yield, also the reduction in the growth and development of the plant, caused by wilting and necrosis, affecting delay of floral induction and formation and fruit maturity [41]. According to the species of Cucurbitaceae, the threshold temperature for growth of sensitive cultures is between 8 and 12°C [42]. In the range of 25–30°C, the metabolic rates increase exponentially. Under these thresholds, many horticultural crops suffer physiological disorders which, according to intensity and length of exposure, subsequently lead to irreversible damage and death of the plant [43]. As an efficient alternative to control the temperature, the use of rootstocks is presented; since there are commercial cultivars tolerant to low temperatures, these rootstocks are recognized as a promising tool [44].

The success of the grafting depends on several factors, including union and compatibility of the graft, quality and age of seedlings, quality of the union, and post-grafting management [45]. In herbaceous species several grafting techniques have been used, and most of them coincide in some general criteria, such as performing it in the first stages of development of the plants (presence of cotyledonous leaves or first true leaves), plants under controlled conditions of temperature and environmental humidity during the period of formation of the union callus, and the subsequent acclimatization to environmental conditions.

4.1 Herbaceous grafts

The most common graft is the approach. The two individuals are sown at the same time, and when they reach 12–15 cm in height (four or five leaves), a cut is made inclined downward with a knife. This cut is made in the space of the stem between the cotyledonal leaves and the first leaves of the rootstock. The cut should be minimal and only reach half of the herbaceous stem. In the same way and in the same position, the stem of the graft is cut; instead, it will be directed upward so that the two small lips can fit as closely as possible. Finally, the grafting point is closed with small pincers or a little aluminum foil like band or some fixation device. To simplify the handling and reduce the time invested in the graft, the plants are removed from their pots before the operation and just after the graft are put back in the same pots to which soil is added, as if it were a transplant. In conditions of temperature of about 20–25°C and with a high humidity (covered with plastic bags), from 8 to 10 days, the graft will have joined, and it can proceed to cut the aerial part of the rootstock and the basal area of the graft [46].

Simple splice graft. A diagonal cut is made through the rootstock seedling just above the cotyledons. On the cut end of the pattern, a piece of thin-walled polyethylene pipe, of the appropriate diameter, is slid to give a good fit. The basal end of the scion receives a diagonal cut similar in length and inclination to that made in the pattern. The prong is slid into the plastic tube until the two cut surfaces are in close contact. The tube is held in place until healing occurs, about 12 days after grafting. If there are no leaves and the buds have not grown, the tube can be removed by sliding it over the scion; otherwise it can be cut with a razor blade [1].

In another procedure used to graft on herbaceous rootstocks, the cleft graft is used (but with a single scion), which consists of making a cut in the stem of the variety 1.5 cm below the cotyledons and making a bevel of 0.6–1.0 cm at its extreme; in the rootstock the apical bud is removed, and a slit is made between the cotyledons, to the center of the stem and down to 1–1.5 cm in length; then the graft union is inserted and tied with rubber bands or latex adhesive tape. To prevent the grafted plant from drying out, it is covered with a polyethylene bag, placed in the shade until the graft has healed, and then the plastic cover is removed [1].

Lateral slit graft. This method is practiced by making a cut in the rootstock above the first leaves and practicing a slight lateral incision directed downward (almost to the middle of the stem) along the space between the leaf that has not been cut and the two cotyledonal leaves (between 1 and 2 cm below the cutoff point). Then, the aerial part of the graft is separated, wedge-shaped and inserted into the lateral crack of the rootstock, and tied. The leaves of the rootstock are left to allow continuity of the absorption activity of the rootstock plant and to favor the union of the scion. Once the graft has been welded, it must be removed with the part of the stem that was left, as it could develop the axillary bud of the leaf and cause the graft to fail [46].

5. Grafting experiments in horticultural crops in Michoacan, Mexico

Given the phytosanitary situation presented by the horticultural species in the State of Michoacan, the use of rootstocks with specific characteristics offer an option for the recovery of soils, without repercussion in the environment.

So in integrated management, one of the strategies is plant resistance, where the technique of grafting plays fundamental importance; in Mexico, there are few documented works on grafts in vegetables and their resistance to pests and diseases [47, 48]; however, graft tests have been performed on tomato, watermelon, and papaya with spontaneous and cultivated plants and with positive results. Although it is true, in Michoacan, Mexico, this technique has not been fully exploited. In the State of Michoacan, it is new and innovative in the cultivations of Solanaceae, Cucurbitaceae, and Caricaceae.

5.1 Grafting in tomato

In Solanaceae, particularly the tomato as a species very susceptible to the attack of phytophagous insects and soil pathogens, apparently *Solanum lycopersicum var. cerasiforme* as a tomato rootstock shows resistance to the fungus *Alternaria solani* [49] and tolerance to psyllid *Bactericera cockerelli* [50] and to the aphid complex [51]. Likewise, although this rootstock comes from different geographical points, it does not demerit the phenological and fruit characteristics of the tomato placed as a graft; it also favors fruit yield [52]. These qualities served as the basis for developing the broader study [53].

Based on the above, with the objective of evaluating the incidence of the main diseases in tomato grafts on the rootstock *S. lycopersicum* var. *cerasiforme* collected in three regions of Michoacan and a collection from the State of Tabasco, Mexico, the cv. Toro® tomato commercial was used as a graft. The experiment was carried out in the Apatzingan Valley, Municipality of Paracuaro, Michoacan, Mexico. In the management of the plantation, the use of pesticides was avoided. The evaluation integrated six tomato grafts: Grafted Small Apatzingan (G-SAp), Grafted Big Apatzingan (G-BAp), Grafted Acahuato (G-Ac), Grafted Los Reyes (G-LR), Grafted Jiquilpan (G-Jiq), Grafted Tabasco (G-Tab), and Tomato (Tom)-like control. The treatments were established in field, under a completely randomized experimental block design. Weekly samplings were carried out to determine the incidence and distribution of diseases during the cycle. Sick tissue was collected to determine the causative agent. The analysis of plants with virus symptoms threw positive results, where the *Geminiviridae* group was identified. For viral diseases, incidence and severity were considered. The diseases registered were "damping off" caused by *A. solani-Fusarium* sp. complex and virus. According to the general analysis of the response of the grafts to the incidence of the present diseases, the treatment G-LR showed total resistance to "damping-off," but not to *A. solani-Fusarium* sp. complex, since to this disease, only the treatments G-SAp and G-BAp presented resistance. Regarding viral disease, all treatments were susceptible (**Table 3**). When the incidence of *Geminiviridae* was evaluated based on severity, the results were different. For example, treatments with degree of severity 3 (medium damage) were the G-BAp, G-SAp, G-Tab, and Tom, with percentages of infected plants from 5.26 to 27.27%. Level 4 (total damage) was not present (**Figure 1**).

The use of *S. lycopersicum* var. *cerasiforme* as rootstock does not influence the physical–chemical characteristics (pH, soluble solids, moisture content) of fruits in grafts compared with tomato. However, these characteristics in ecotypes of *S. lycopersicum* var. *cerasiforme* are inferior compared with the grafts and the tomato, that is, the grafted plants and the tomato have pH between 4.45 and 4.52. So, it is suggested that the pH is less acidic than that of the fruits of *S. lycopersicum* var. *cerasiforme*, which is between 4.77 and 5.37 [54]. At respect, it has been observed that in grafted tomato plants, the pH was less acidic (4.04–4.30) than in the plants without grafting (4.35–4.47) [55]; however, this variation was minimal because in

Treatment	*Disease*		
	Damping-off	***A. solani-Fusarium* sp. complex**	**Virosis**
G-BAp	46.00 ± 6.92*ab	0.00 ± 0.00*a	52.67 ± 21.12**a*
Tom	25.00 ± 10.00bc	16.66 ± 10.40a	17.03 ± 13.96*a*
G-SAp	16.66 ± 11.54bc	0.00 ± 0.00a	30.33 ± 15.17*a*
G-Ac	10.23 ± 11.70cd	5.12 ± 4.43a	12.93 ± 7.88*a*
G-Jiq	8.33 ± 10.40cd	1.66 ± 2.88a	19.33 ± 7.37*a*
G-Tab	6.56 ± 6.50cd	6.66 ± 6.66a	21.00 ± 8.71*a*
G-LR	0.00 ± 0.00d	4.44 ± 3.84a	15.07 ± 13.79*a*

Means ± standard deviation, data subjected to arcsine transformation of the square root of the ratio. Different letters in the same column indicate significant differences between means (Tukey, 0.05).

Table 3.
Incidence of "damping-off," A. solani-Fusarium sp. complex and virosis in tomato grafts under field conditions. Paracuaro, Michoacan [53].

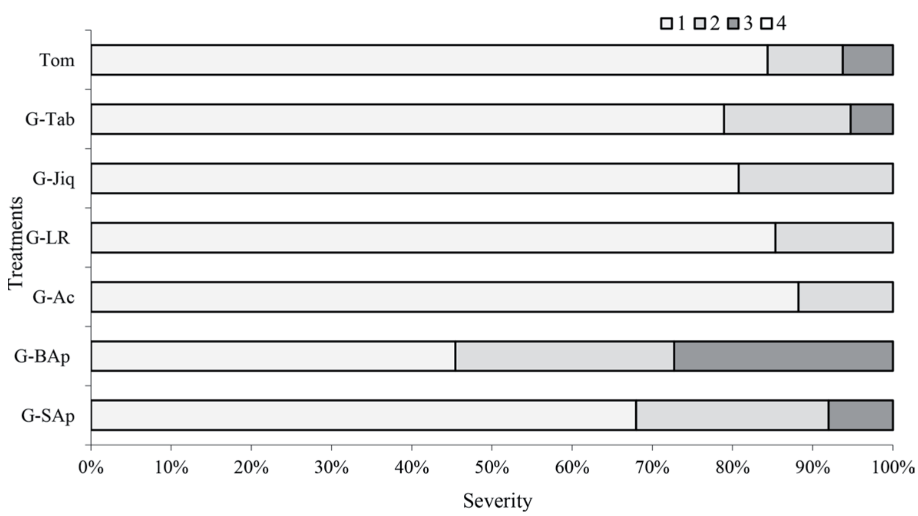

Figure 1.
Distribution of severity levels of Geminiviridae in different epidemics of tomato grafting under field conditions in Paracuaro, Michoacan: 1 = no damage, 2 = start of damage, 3 = medium damage, 4 = total damage [53].

commercial varieties, the pH is between 4.2 and 4.4 [14]; other authors [56] did not find significant statistical differences between grafts (4.33–4.41) and control 4.34.

Regarding soluble solids, the concentration in fruits was higher in *S. lycopersicum* var. *cerasiforme* with 7.5–7.75°Brix, unlike the grafts and the tomato with values 6.25–7.0°Brix, respectively [54]. The range of the cultivated varieties is between 4.5 and 5.5°Brix; although more than the varietal character, the agroecological factors influence the content of soluble solids because they can vary the °Brix for fruits of the same variety between 4 and 7 [14]. Other studies have not found differences in the °Brix of grafted and ungrafted plants [52], with values of 3.95–4.7°Brix for grafted plants and 3.95–4.95° Brix for non-grafted plants. Similarly, others report values of 3.1–4.0°Brix in grafts and 3.68°Brix in control [56]. The humidity percentage had a similar behavior only that *S. lycopersicum* var. *cerasiforme* presented lower humidity (88.39–91.33%) in comparison to the grafts and the tomato that had values of 93.99–97.44% humidity [54], differences that may be due to the wild origin of *S. lycopersicum* var. *cerasiforme*. The humidity values reported for the tomato are 94 and 95% [14, 57], which are similar to those found in our grafts.

5.2 Grafting on watermelon

The species of Cucurbitaceae that are commonly grafted are watermelon, cantaloupe, and cucumber. There are some rootstocks compatible with the three species [37]. Regarding diseases in cucurbitaceae, of the most important and that has been achieved better by grafting are those caused by pathogenic fungi, the wilt caused by *F. oxysporum* f. sp. *niveum*, being the most important. Pathogenic viruses transmitted from the soil and root-knot nematodes [58] are also important. Currently, in several countries hybrid rootstocks of wild origin or cultivated species are resistant to *Meloidogyne* spp. [4].

During the 1980s, the region of Apatzingan Valley, Michoacan, was positioned among the seven main states producing watermelon, with the advantage of presenting the ideal environment for cultivation during the autumn-winter cycle; however, their participation gradually decreased by more than 50% of the area originally intended for cultivation [59]. This reduction in agricultural land is attributed to several factors, such as the lack of more information about the evaluation and application of technical components for crop management and sustainable control of pests and diseases. Particularly, the wilt caused by *Fusarium* is considered a disease that gradually deteriorates the vigor of watermelon and cantaloupe [23]. In the Apatzingan Valley, its control came to represent 60% of the cost of cultivation, the effect of which had an impact on the quality and quantity of the crop, the reason that explains the reduction of the area dedicated to its cultivation. With respect to the root-knot nematode, it has been associated with different crops in the same region; in fact in a reported study [24], *Meloidogyne* spp. was identified in watermelon and cantaloupe and was considered a potential danger for Cucurbitaceae, since its presence causes galls in roots and decreases production. Therefore, with the objective of evaluating two rootstocks for watermelon, in two plantation distances (densities), tests were developed in a property located in the Apatzingan Valley, Michoacan, with a history of phytosanitary problems. To confirm the above in the selection of the study site in different plots, microbiological soil and root analyses were carried out to determine the existence of nematodes, bacteria, and fungi, particularly *Fusarium* (**Table 4**).

The experimental design proposed was randomized complete blocks. Six treatments were evaluated, triploid watermelon grafts on two rootstocks and triploid watermelon without grafting, all at two planting densities (4166 and 2083 plants/ha), conforming the following treatments: triploid watermelon graft on "Super Shintosa" rootstock at a density of 4167 plants per hectare (G-RSS 100), triploid

Sampled land	Nematodes			Bacteria	Presence of *Fusarium*
	Presence	Cucurbitaceae			
		Tolerance limit (No.)	Economic threshold (No.)		
Crucitas	+	2–49	≥50	2.94×10^{9} *	+
Y Griega Pozos	+			2.53×10^{7}	+
Y Griega	+			1.39×10^{6}	+
Cd. Morelos	+			3.01×10^{6}	+

CFU/g d.s. = colony-forming units per gram of dry soil.

Table 4.
Results of the microbiological analysis of infested soils of agricultural lands of the Apatzingan Valley, Michoacan [60].

Treatments	Triploid crunchy red					
	Soluble solids (°Brix)	Pulp hardness (kg/cm^2)	pH	Bark width (cm)	Pulp width (cm)	Moisture content (%)
G-RSS 100	11.72	1.94 bc	5.20	1.43 c	15.59 b	91.13
G-RSS 50	11.78	2.02 ab	5.30	1.45 bc	17.63 a	91.16
G-RR 100	11.74	2.12 a	5.27	1.50 ab	17.29 a	90.97
G-RR 50	11.53	2.11 a	5.27	1.45 bc	17.27 a	90.94
C-100	11.46	1.86 c	5.29	1.53 a	10.67 d	91.83
C-50	11.46	1.70 d	5.27	1.53 a	13.55 c	91.27
P	0.17	0.00	0.87	0.00	0.00	0.28
C.V.	1.59	2.79	1.91	1.42	3.93	0.51

Table 5.
Qualitative aspects of watermelon fruits grafted in two population densities [60].

watermelon graft on "Super Shintosa" rootstock at a density of 2083 plants per hectare (G-RSS 50), triploid watermelon graft on "Robusta" rootstock at a density of 4167 plants per hectare (G-RR 100), triploid watermelon graft on "Robusta" rootstock at a density of 2083 plants per hectare (G-RR 50), and triploid watermelon at a density of 4167 plants per hectare (C-100) and triploid watermelon at a density of 2083 plants per hectare (C-50) as controls. Regarding the qualitative characteristics of the fruits, the statistical analysis showed significant differences in the variables hardness of pulp, width of bark, and width of pulp, where, with the exception of the width of bark, the control treatments were exceeded in both densities. Although statistically there were differences between rootstocks (G-RSS and G-RR), with the values so close, it is presumed that the use of the graft does not alter the quality of the fruit (**Table 5**).

Regarding the phytosanitary condition, the rootstocks showed tolerance in the presence of *Fusarium* and nematodes, since in most of the variables the control was exceeded [60]. So, it is important to mention that in watermelon two main phytosanitary problems handled by the grafts are *Fusarium* wilt and nematode damage. The first case is a disease that gradually deteriorates the vigor of the plant until it is eliminated [61]. The Robusta rootstock followed by the Super Shintosa rootstock in high density favor greater efficiency related to productivity, but between the two rootstocks, Super Shintosa is sensitive to the presence of nematode [62]. It should be mentioned that watermelon is pursued to achieve the management of diseases at ground level. To avoid the use of methyl bromide, the rootstock *Cucurbita maxima* × *Cucurbita moschata* has been successfully used. Nevertheless, in the presence of nematodes, this rootstock is usually susceptible [63]. The biotic and abiotic stress of plant species derives from the soils condition and represents the greatest limitation for horticultural productivity, but when risks are minimized, it can be viable. It is important to highlight that the use of specific rootstocks to provide tolerance and/or resistance to limiting factors for the normal development of the plant is largely due to the fact that they provide a more developed and vigorous root system compared to non-grafted plants [64]. As is known, one of the main problems facing the production of watermelon in the world is the damage caused by *Fusarium*. The disinfection with methyl bromide at first gave good results, but with the time the disease generated resistance, and the use of this product has been banned; currently, the use of the graft as an alternative has reduced the problem.

5.3 Grafting in papaya

In Michoacan, ecotypes of papaya have been developed [65]. Being a predominantly agricultural territory, the region has been severely affected by the system of monoculture type and the indiscriminate use of agrochemicals, which has caused resistance of pests and diseases difficult to control through conventional systems [66]. For this reason, the Caricaceae family, particularly papaya, has the potential to be grafted to explore, in addition to the productive and phytosanitary aspect, the appearance of the sexing of plants, knowing that the preferred plants are those that emit the elongata hermaphrodite flower type and that it gives rise to elongated or marketable fruit, which is possible through grafting [67].

Therefore, in the Apatzingan Valley, experimental works of grafting in papaya were developed. The region has a semidry warm climate condition (the wettest of the semidry warm ones) with summer rains and a dominant volcanic (clayed) soil type. In order to generate and adapt a grafting method for papaya, experimental trials were carried out. Two grafting methods were tested, along with the strategies employed in vegetables, which were used for the formation of grafted papaya plants. During the development of the trials, modifications were made. In the first evaluation, two grafting methods, approach graft G.A. and cleft graft G.C. [5], and two clamping devices, lead band (G.A.B. and G.C.B.) and plastic clip (G.A.P. and G.C.P.), were compared. The response in the percentage of survival of the methods of approach and cleft grafts and fastening with lead band and clip was variable (**Figure 2**).

In the second evaluation, there were two modifications to the first graft method, called modified approach graft (G.A.M.) with two types of cuts (G.A.M.C1 and G.A.M.C2). With respect to the cleft graft, a modification was also proposed (G.C.M.) (**Figure 3**). As noted, in the second evaluation, two modifications to the evaluated methods arose, and a method called modified cleft graft (G.C.M.) was also incorporated. In **Figure 3**, the percentage values on the grafting of the graft approach methods are presented (G.A.M.C1 and G.A.M.C2). Due to its high percentage of survival (almost 90%), the treatment G.A.M.C2 is acceptable and exceeds the expectations for its use in papaya, under the conditions evaluated.

In a third evaluation, the modified approach graft method (G.A.M.C1) was tested in three containers. With respect to the election of containers, it includes the trays of 128 and 200 cavities (G.A.M.128 and G.A.M.200) and the plastic bag (G.A.M.B.). The results showed that the G.A.M.B. achieved 89% of survival (**Figure 4**).

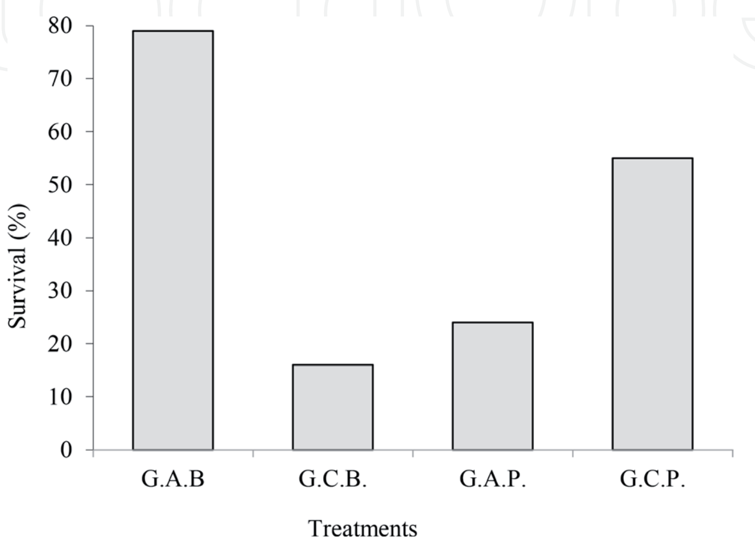

Figure 2.
Methods of approach and cleft graft and two fixation devices [68].

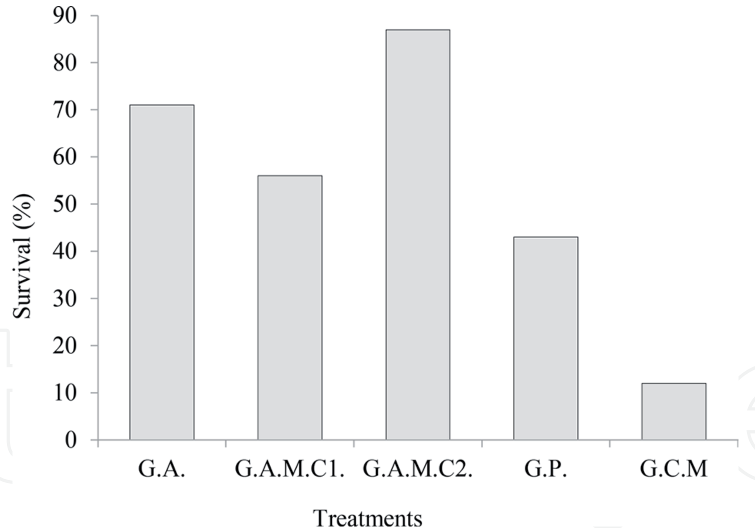

Figure 3.
Modified approach and cleft graft methods and two fixation devices [68].

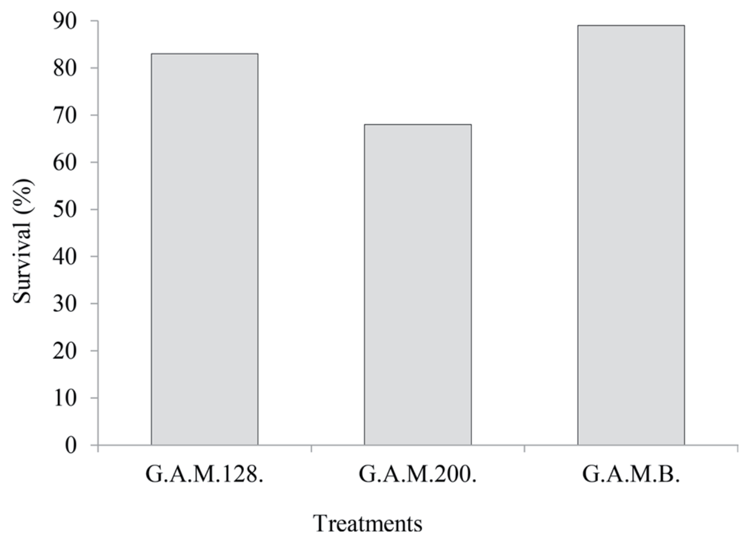

Figure 4.
Modified graft method in different containers [68].

Recapitulating, of the three evaluations, the approach graft method subjected by lead band (G.A.B.) and the modified method (G.A.M.C2.) were the most effective with 79 and 87% of survival, respectively. As for the containers used, the grafted plant with the highest yield corresponded to the use of a bag (G.A.M.B), surpassing the tray containers [68].

In another experiment, with the objective of evaluating the behavior of grafted plants and the quality of the plants, an experiment was established with five treatments formed by different combinations of rootstock and graft, in commercial genotypes. Two phases were evaluated, before and after the transplant. In the nursery, a papaya seedling was produced in a plastic bag container. The genotypes used were the varieties "Gibara" (G), "BS" (BS), "BS2" (BS2) and "Maradol" (M), and later they would serve as rootstocks (R) and grafts (G). The grafting method used was the modified approach. Five treatments were used: R. G × G. BS, R. BS × G. G, R. BS2 × G. BS, R. BS × G. BS2, and R. BS2 × G. M. The variables evaluated were the percentage of post-graft survival (prior to transplant) and percentage of post-graft survival in the field (after transplant). In the field, to determine the quality of the grafted plant in its post-graft stage, a grading scale designed under three key levels was used: N1 = vigorous, robust plant, upright leaves, normal terminal bud, does

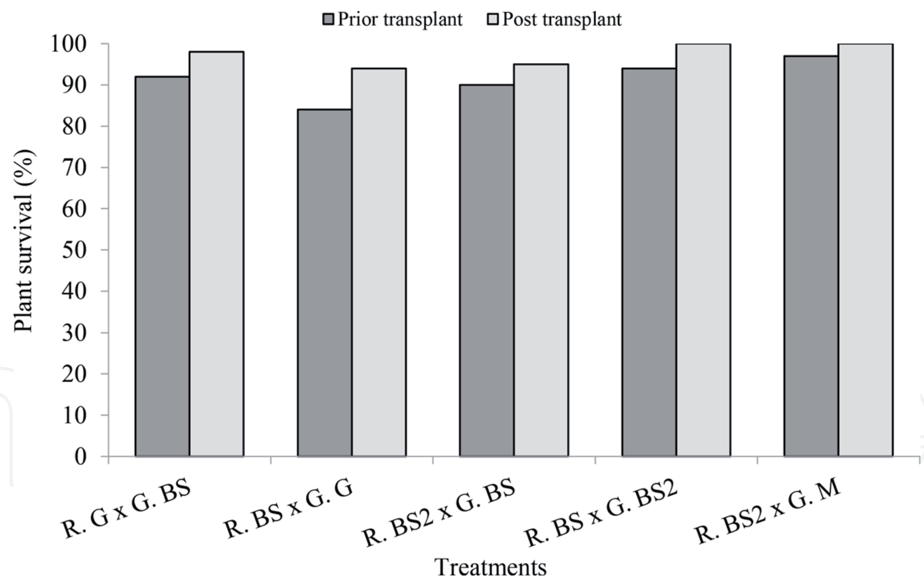

Figure 5.
Quality of grafted papaya plant prior and post transplant.

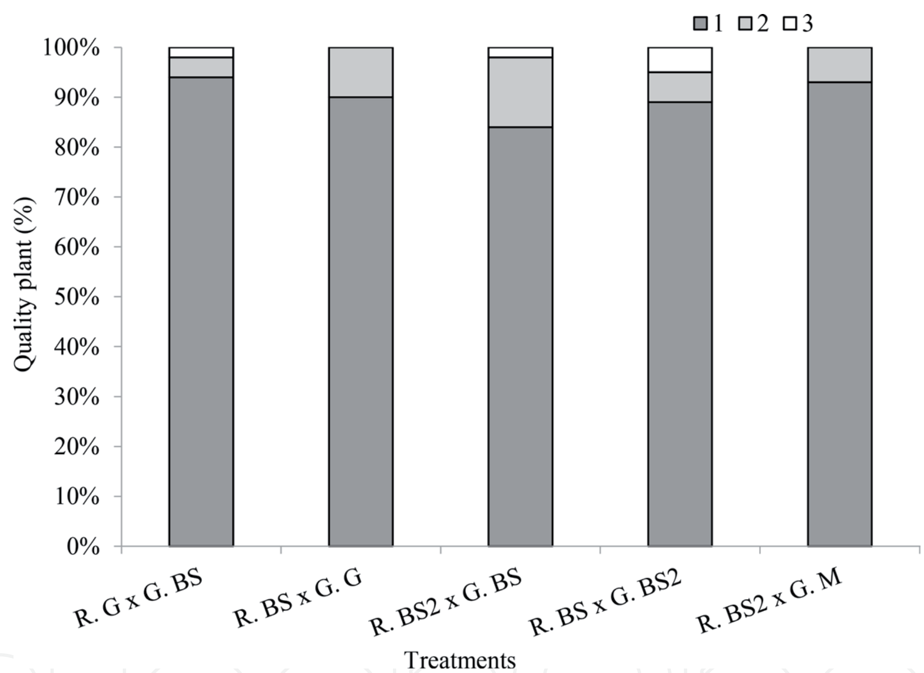

Figure 6.
Quality level of grafted papaya plant [69].

not present physical alterations in the union of the graft; N2 = vigorous plant, some leaves upright, slightly physical alterations are perceived in the union of the graft; and N3 = stressed plant appearance, weak terminal bud, contrast in stem coloration near the graft. The results obtained from the survival of the grafted papaya plant before and after the transplant are presented in **Figure 5**. The modified approach graft method responded positively in both situations, since most of the treatments exceeded well above 80% of survival, which is acceptable for the papaya species, due to its recent exploration on the subject. When making the comparison of survival between the pre- and posttransplant conditions, the values were generally lower when the pretransplant condition was registered.

In relation to plant quality, based on the three-level assessment scale, the results are presented in **Figure 6**. In general, the five grafting treatments presented level 1 (N1 = vigorous, robust plant, upright leaves, bud normal terminal, does not present physical alterations in the union of the graft) in greater percentage than levels 2 and 3;

and between treatments, R. G × G. BS, R. BS × G. G., and R. BS2 × G. M were superior with more than 90% in the first level. In level 2 (N2 = vigorous plant, some upright leaves, slightly physical alterations are perceived in the union of the graft), which was desirable to occur in a smaller proportion, only the treatments R. BS × G. G. and R. BS2 × G. BS. presented between 10 and 14%, respectively; in the rest of treatments, it was presented between 4 and 7%. This circumstance can be attributed to the fact that the plants registered under this characterization are possibly still in the postgraft recovery stage, which is caused by defect in the operation of the graft; however the situation can be reversed. Finally, level 3 (N3 = appearance of stressed plant, weak terminal bud, contrast in the coloration of the stem close to the graft), except for the treatments R. BS × G. G., and R. BS2 × G. M., did not have this condition. The other treatments presented between 2 and 5%. Although they are grafted plants that will be discarded, the percentage can be considered tolerant (**Figure 6**).

Both the modified approach graft technique and the combination of grafted genotypes in the post-graft stage before and after the transplant expressed the percentage survival condition acceptable. With the technique surpassed of the papaya graft, the bases are established to explore other aspects oriented to the management of the crop.

6. Conclusion

The species with potential for the use of graft in the Apatzingan Valley Michoacan, Mexico, are from the Solanaceae family, the tomato, the tomato from shell (*Physalis ixocarpa*), chili pepper, and the eggplant; from the Cucurbitaceae family, watermelon, cantaloupe, and cucumber; and from the Caricaceae family, the papaya, the latter in the first order to attend first to the aspect of sexing plants, where plants of the elongata hermaphrodite flower type should be selected, and in a second order to the incidence of viral diseases.

Therefore, the graft in the State of Michoacan is an alternative viable solution for the management of the mentioned crops, since it offers promising results, so its adoption can be a reality. It is also worth mentioning that the advantages of using grafted plants are much, since doing a count, is a non-polluting technique, it gives vigor to the plants, and is possible to lengthen the productive cycle. In general, the root system of the rootstocks is denser and wider; therefore, the plant has greater exploration capacity in the soil and in turn greater absorption of water and nutrients. Also, the fact of tolerating the presence of soil pests such as nematodes and harmful pathogens, plants can produce fruits and in most cases increase yields. By itself, the use of grafted plants helps to improve the conditions of the crop, but also, if this technique is included in a program of integrated management of pests and diseases, it can ensure the success of the production of different crops.

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References

[1] Hartmann HT, Kester DE. Propagación de plantas, principios y prácticas. 2nd ed. México: CECSA; 1988. 760 p

[2] Garner RJ. The grafter's Handbook. London: Editorial Cassell; 2000. 323 p

[3] Fernández-Garcí N, Martínez V, Carvajal M. Fruit quality of grafted tomato plants grown under saline conditions. The Journal of Horticultural Science and Biotechnology. 2004;**79**(6):995-1001. DOI: 10.1080/14620316.2004.11511880

[4] González FM, Hernández A, Casanova A, Depestre T, Gómez L, Rodríguez MG. Vegetable grafting: Alternative for the management of soil pests. Revista de Protección Vegetal. 2008;**23**(2):69-74. ISSN 2224-4697

[5] Lee JM, Oda M. Grafting of herbaceous vegetable and ornamental crops. Horticultural Reviews. 2003;**28**:61-124. DOI: 10.1002/9780470650851.ch2

[6] Rivero RM, Ruiz JM, Romero L. Role of grafting in horticultural plants under stress condition. Journal of Food, Agriculture and Environment. 2003;**1**(1):70-74. DOI: 10.1234/4.2003.318

[7] Leonardi C, Romano D. Recent issues on vegetable grafting. Acta Horticulturae. 2004;(631):163-174. DOI: 10.17660/ActaHortic.2004.631.21

[8] Martínez-Ballesta MC, López-Pérez L, Hernández M, López-Berenguer C, Fernández-García N, Carvajal M. Agricultural practices for enhanced human helth. Phytochem Revviews. 2007;**7**(2):251-260. DOI: 10.1007/s11101-007-9071-3

[9] Fernández-García N, Martínez V, Carvajal M. Effect of salinity on growth, mineral composition, and water relations of grafted tomato plants. Journal of Plant Nutrition and Soil Science. 2004;**167**(5):612-622. DOI: 10.1002/jpln.200420416

[10] White JW, Castillo JA. Relative effect of root and shoot genotypes on yield of common bean under drought stress. Crop Science. 1989;**29**(2):360-362. DOI: 10.2135/cropsci1989.0011183X002900020026x

[11] Ruiz-Sifre G, Dole JM, Kahn B, Richardson PE, Ledford J. Correlation of poinsettia graft union development with transmission of the free-branching characteristic. Scientia Horticulturae. 1997;**69**(3-4):135-143. DOI: 10.1016/S0304-4238(97)00001-0

[12] Sagarpa editor. Food, Agriculture and Fishing Information Service (SIAP, by its acronyms in Spanish). Food and Agricultural Atlas. 1st ed. Mexico City; 2017. 231 p

[13] SIAP-SAGARPA. Statistics of National Rice Production [Internet]. 2017. Available from: http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/AvanceNacionalCultivo.do [Accessed: 2018-07-02]

[14] Nuez F. Desarrollo de nuevos cultivares. In: Nuez VF, editor. El cultivo del tomate. España: Ediciones Mundi-Prensa; 1995. pp. 626-669

[15] Liu D, Trumble JT. Tomato psyllid behavioral responses to tomato plant lines and interactions of plant lines with insecticides. Journal of Economic Entomology. 2004;**97**(3):1078-1085. DOI: 10.1603/0022-0493(2004)097[1078:TPBRTT]2.0.CO;2

[16] Casteel CL, Walling LL, Paine TD. Behavior and biology of tomato psyllid, *Bactericera cockerelli*, in response to the Mi-1.2 gene. Entomologia

Experimentalis et Applicata. 2006;**121**:67-72

[17] Tello JC, Mural J. Enfermedades no víricas del tomate. In: Nuez VF, editor. El cultivo del tomate. España: Ediciones Mundi-Prensa; 1995. pp. 524-563

[18] Hoyt E. Conserving the Wild Relatives of Crops. Delaware, United States of America: Addison-Wesley Iberoamericana; 1992. 52 p. ISBN: 0-201-51830-3

[19] Eigenbrode SD, Trumble JT. Resistance to beet armyworn, Hemipterans, and *Liriomyza* spp. in *Lycopersicon* accesiones. Journal of American society for. Horticultural Science. 1993;**118**:442-456. ISSN: 0003-1062

[20] Pérez GM, Márquez SF, Peña LA. Mejoramiento genético de hortalizas. México: Universidad Autónoma Chapingo; 1997. 380 p

[21] Restrepo SEF, Vallejo CFA, Lobo AM. Evaluación de poblaciones segregantes producidas a partir de cruzamientos entre tomate cultivado y la accesión silvestre PI134418 de *Solanum habrochaites* var. *glabratum* resistente al pasador del fruto. Acta Agronomica. 2008;**57**(1):1-8. ISSN: 2323-0118

[22] Kogan M. La resistencia de la planta en el manejo de plagas. In: Metcalf RL, Luckman WH, editors. Introducción al manejo integrado de plagas. México: Limusa-Noriega; 1990. pp. 123-172

[23] Bruton BD. Soilborne diseases in Cucurbitaceae: Pathogen virulence and host resistance. In: McCreight J, editor. Cucurbitaceae ´98. Alexandria, Virginia: ASHS Press; 1998. pp. 143-146

[24] Sosa-Moss C. *Meloidogyne incognita* nematodo agallador radicular del melón en el Valle de Apatzingán, Michoacan. Informe Técnico. Chapingo México: Colegio de Postgraduados; 1971

[25] Ban D, Zanić K, Dumicić G, Gotlin-Culjak T, Goreta-Ban S. The type of polyethylene mulch impacts vegetative growth, yield, and aphid populations in watermelon production. Journal of Food, Agriculture and Environment. 2009;**7**:543-550. ISSN: 1459-0263

[26] Goreta S, Perica S, Dumicić G, Bućan L, Zanić K. Growth and yield of watermelon on polyethylene mulch with different spacings and nitrogen rates. HortScience. 2005;**40**(2):366-369 ISSN: 2327-9834

[27] Canales CR, Sánchez BJA. Cadena agroalimentaria de sandía. Caracterización de los eslabones de la cadena e identificación de los problemas y demandas tecnológicas. Campeche: INIFAP. COFUPRO. FUPROCAM; 2003. p. 103

[28] Pérez-González JL, Sánchez-Cohen I, Mendoza-Moreno FS, Inzunza-Ibarra MA, Cueto-Wong JA. Productividad y rendimiento de sandía por efecto del agua en diferentes condiciones de manejo. Revista Chapingo Serie Horticultura. 2003;**9**(2):209-223. DOI: 10.5154/r.rchsh.2001.08.049

[29] Fitch MM, Leong T, Akashi L, Yeh A, White S, De la Cruz A, et al. Growth and yield of clonally propagated and seedling-derived papayas. I. Growth. II. Yield. The Journal of Horticultural Science and Biotechnology. 2005;**40**(5):1283-1290. ISSN: 2380-4084

[30] Hossain M, Rahman N, Islam S, Joarder O. High efficien plant regeneration from petiole explants of *Carica papaya* L. through organogenesis. Plant Cell Reports. 1993;**13**(2):99-102. ISSN: 1432-203X

[31] Elder RJ, Macleod WNB, Reid DJ, Gillespie RL. Growth, yield and phenology of 2 hybrid papayas (*Carica papaya* L.) as influenced by method of water application. Australian

Journal of Experimental Agriculture. 2000;**40**(5):739-746. DOI: 10.1071/EA99107

[32] Senthilkumar S, Kumar N, Soorianathasundaram K, Jeya-Kumar P. Aspects on asexual propagation in papaya (*Carica papaya* L.)- a review. Agricultural Reviews. 2014;**35**(4):307-313. DOI: 10.5958/0976-0741.2014.00919.2

[33] Allan P. Phenology and production of *Carica papaya* 'honey gold' under cool subtropical conditions. Acta Horticulturae. 2007;(740):217-223. DOI: 10.17660/ActaHortic.2007.740.26

[34] Lima de LA, Naves RV, Yamanishi OK, Pancoti HL. Behavior of three papaya genotypes propagated by grafting in Brazil. Acta Horticulturae. 2010;(851):343-348. DOI: 10.17660/ActaHortic.2010.851.52

[35] Lange AH. Reciprocal grafting of normal and dwarf solo papaya on growth and yield. Horticultural Science. 1969;**4**(4):304-306

[36] King SR, Davis AR, Liu W, Levi A. Grafting for disease resistance. HortScience. 2008;**43**(6):1673-1676 ISSN: 2327-9834

[37] King SR, Davis AR, Zhang X, Crosby K. Genetics, breeding and selection of rootstocks for solanaceae and cucurbitaceae. Scientia Horticulturae. 2010;**127**(8):106-111. DOI: 10.1016/j.scienta.2010.08.001

[38] Santos LM, Fontanetti VM, Minami K, Tessarioli NJ. Evaluation of graft supports for Japanese cucumber. Scientia Agricola. 2000;**57**(1):169-172. DOI: 10.1590/S0103-90162000000100027

[39] Santos HS, Goto R. Sweet pepper grafting to control *Phytophthora* blight under protected cultivation. Horticultura Brasileira. 2004;**22**(1):45-49. DOI: 10.1590/S0102-05362004000100009

[40] Toppino L, Vale G, Rotino GL. Inheritance of *Fusarium* wilt resistance introgresed from *Solanum aethiopicum* Gilo and Aculeatum groups into cultivated eggplant (*S. melongena*) and development of associated PCR-based markers. Molecular Breeding. 2008;**22**(2):237-250. DOI: 10.1007/s11032-008-9170-x

[41] Ahn SJ, Im YJ, Chung GC, Cho BH, Suh SR. Physiological responses of grafted-cucumber leaves and rootstock roots affected by low root temperature. Scientia Horticulturae. 1999;**81**(4):397-408. DOI: 10.1016/S0304-4238(99)00042-4

[42] Hansen LD, Afzal M, Breidenbach RW, Criddle RS. High and low temperature limits to growth of tomato cells. Planta. 1994;**195**(1):1-9. ISSN: 14322048

[43] Venema JH, Linger P, Van Heusden AW, Van Hasselt PR, Brüggemann W. The inheritance of chilling tolerance in tomato (*Lycopersicon* spp.). Plant Biology. 2005;**7**(2):118-130. DOI: 10.1055/s-2005-837495

[44] Rouphael Y, Schwarz D, Krumbein A, Colla G. Impact of grafting on product quality of fruit vegetable crops. Scientia Horticulturae. 2010;**127**(2):172-179. DOI: 10.1016/j.scienta.2010.09.001

[45] Kawaguchi M, Taji A, Backhouse D, Oda M. Anatomy and physiology of graft incompatibility in solanaceous plants. The Journal of Horticultural Science and Biotechnology. 2008;**83**(5):581-588. DOI: 10.1080/14620316.2008.11512427

[46] Peil RM. Grafting of vegetable crops. Ciencia Rural. 2003;**33**(6):1167-1169. DOI: 10.1590/S0103-84782003000600028

[47] Alvarez HJC, Cortez MH, Garcia RI. Injertos de jitomate (*Solanum lycopersicum* L.) en parientes silvestres como fuente de resistencia a plagas. In: Estrada VEG, Equihua MA, Chaires GM, Acuña SJA, Padilla RJR, Mendoza EA, editors. Entomologia Mexicana. 1ra ed. Vol. 8. Mexico: Sociedad Mexicana de Entomologia; 2009. pp. 551-555. ISBN 968-839-559-2

[48] Cortez-Madrigal H. Injertos en parientes silvestres de jitomate y su potencial en el manejo de plagas. Entomología Mexicana. 2008;**7**:570-574

[49] Méndez-Inocencio C, Cortez-Madrigal H, Muñoz-Ruíz C, Ochoa-Gaytan E. El tinguaraque *Lycopersicon esculentum* var. *cerasiforme* como fuente de resistencia a plagas y enfermedades en Michoacan. In: Memorias del 2do. Zamora, Michoacan: Congreso Estatal de Ciencia y Tecnología; 2006. p. 64

[50] Cortes MH, Alvarez HJC. Incidencia y daño de insectos fitófagos en injertos de jitomate sobre parientes silvestres. In: Memorias del IX Simposio Internacional y IV Congreso Nacional de Agricultura Sostenible; Boca del Rio Veracruz México; 2007. p. 296

[51] Alvarez HJC, Cortez MH. Incidencia de insectos fitófagos en injertos de jitomate (*Solanum lycopersicum* L.) sobre parientes silvestres. In: Memorias del 5to. Morelia Michoacan Mexico: Congreso Estatal de Ciencia y Tecnología; 2009. pp. 1-6

[52] Alvarez HJC, Cortez MH, Garcia RI. Injertos de jitomate en ecotipos silvestres de *Solanum lycopersicum* var. *Cerasiforme*. In: Memorias del XI. Chapingo Mexico: Congreso Nacional de Ciencias Agronómicas; 2009. pp. 1-2

[53] Alvarez HJC, Cortez MH, Ceja TLF. Incidence of diseases in grafters of tomato (*Solanum lycopersicum*) on its wild relative. In: Memorias del XI Congreso Internacional/ XXXVI. Acapulco Gerrero Mexico: Congreso Nacional de la Sociedad Mexicana de Fitopatología; 2009. pp. 1-6

[54] Alvarez HJC. Caracterización agronómica e incidencia de enfermedades de injertos de jitomate en jitomate silvestre. In: Memorias del XIII. Chapingo México: Congreso Nacional de Ciencias Agronomicas; 2011. pp. 316-317

[55] Coutinho CS, Fermino SAC, Dos Santos BA, Araújo DCL, Da Silva LC. Potential of Hawaii 7996 hybrid as rootstock for tomato cultivars. Bragantia. 2006;**65**(1):89-96. ISSN: 1678-4499

[56] Khah EM, Kalawa E, Mavromatis A, Chachalis D, Goulas C. Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* mill.) in greenhouse and open-field. Journal of Applied Horticulture. 2006;**8**(1):3-7. ISSN: 0972-1045

[57] Valadez LA. Producción de hortalizas. México: Limusa; 1998. 298 p

[58] Davis AR, Perkins-Veazie P, Sakata Y, López-Galarza S, Maroto JV, Lee SG, et al. Cucurbit grafting. Critical Reviews in Plant Sciences. 2008;**27**:50-74. DOI: 10.1080/07352680802053940

[59] Alvarez HJC, Castellanos RJZ, Camacho FF, Aguirre MCL, Rangel LJA, Huitron RMV. Portainjerto y densidad de poblacion sobre la sanidad, rendimiento y calidad de frutos de sandia en lotes con nematodos y *Fusarium*. In: Memorias del XIV. Chapingo Mexico: Congreso Nacional de Ciencias Agronomicas; 2012. pp. 136-137

[60] Alvarez HJC, Castellanos RJZ, Camacho FF, Aguirre MCL, Rangel LJA, Huitron RMV. Comportamiento de la sandía injertada expuesta a suelos con

problemas fitosanitarios y densidades de plantacion. In: Rangel LJA, Raya PJC, Cervantes, OF, Aguirre MCL, Ramirez PJG, Mendoza EM, editors. 1st. Congreso Nacional de Ciencia y Tecnologia Agropecuaria; Roque Guanajuato Mexico; 2012. p. 265-272. ISBN 978-607-96093-1-3

[61] Alvarez HJC, Castellanos RJZ, Camacho FF, Aguirre MCL, Huitron RMV. Injerto de sandia y distanciamiento entre plantas, expuestas a suelo con *Fusarium* y nematodos. In: Memorias del LIX Annual Meeting of the Interamerican Society for Tropical Horticulture; Septiembre 2-6 2013. Santiago de Queretaro, Queretaro Mexico; 2013. p. 172

[62] Alvarez HJC, Castellanos RJZ, Camacho FF, Aguirre MCL, Rangel LJA, Huitron RMV. Uso de porta-injertos en sandia y distanciamiento para el manejo fitosanitario. In: Memorias del 2°. Roque Guanajuato Mexico: Congreso Nacional de Ciencia y Tecnología Agropecuaria; 2014. p. 72. ISSN: 2448-6620

[63] Alvarez HJC, Castellanos RJZ, Camacho FF, Aguirre MCL, Huitron RMV. Porta-injertos y densidades de poblacion para sandia triploide en Michoacan. In: Memorias del 9°. Morelia Michoacan Mexico: Congreso Estatal de Ciencia Tecnología e Innovación; 2014. pp. 595-597

[64] Guan W, Zhao X, Hassell R, Thies J. Defense mechanisms involved in disease resistance of grafted vegetables. HortScience. 2012;**47**(2):164-170 ISSN: 2327-9834

[65] Alvarez HJC, Castellanos RJZ, Aguirre MCL. Ecotipos silvestres de *Carica papaya* y su potencial como portainjertos. In: Memorias del Tercera Reunion Cientifica Interinstitucional sobre Diversidad Biologica. Mayo 18 2018; Ciudad de Mexico. 2018. p. 71

[66] Alvarez HJC, Valdivia RG, Pardo MS. Seleccion de especies de cucurbitaceas con cualidades robustas para la mejora agronomica a traves del injerto. In: Memorias del Tercera Reunion Científica Interinstitucional sobre Diversidad Biológica; Mayo 18 2018; Ciudad de México. 2018. p. 72

[67] Alvarez HJC, Castellanos RJZ, Aguirre MCL. Desarrollo de injertos de papaya: primera etapa. In: Memorias del 11°. Morelia Michoacan Mexico: Congreso Estatal de Ciencia Tecnología e Innovación; 2016. pp. 1-6. ISSN: 04-2016-082917280600-203

[68] Alvarez HJC, Castellanos RJZ, Aguirre MCL. Comparación entre métodos de injerto en *Carica papaya*. In: Memorias del XVII Congreso Nacional y III Internacional de la Sociedad Mexicana de Ciencias Hortícolas; Nuevo Vallarta Nayarit Mexico; 2017 p. 231-234. ISBN: 978-607-37-0763-3

[69] Alvarez HJC, Castellanos RJZ, Aguirre MCL. Estudio preliminar de materiales de papaya injertado. In: Memorias del XVII. Nuevo Vallarta Nayarit Mexico: Congreso Nacional y III Internacional de la Sociedad Mexicana de Ciencias Horticolas; 2017. pp. 214-217. ISBN: 978-607-37-0763-3