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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

Year	Tomato			Watermelon			Papaya		
	Cultivated area (ha)	Total production (t)	Yield (t·ha ⁻¹)	Cultivated area (ha)	Total production (t)	Yield (t·ha ⁻¹)	Cultivated area (ha)	Total production (t)	Yield (t·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·ha ⁻¹)	Cultivated area (ha)	Total production (t)	Yield (t·ha ⁻¹)	Cultivated area (ha)	Total production (t)	Yield (t·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].

vvssituation 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, staminate, 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	<i>A. solani-Fusarium</i> sp. complex	Virosis
G-BAp	46.00 ± 6.92 ^{ab}	0.00 ± 0.00 ^a	52.67 ± 21.12 ^a
Tom	25.00 ± 10.00 ^{bc}	16.66 ± 10.40 ^a	17.03 ± 13.96 ^a
G-SAp	16.66 ± 11.54 ^{bc}	0.00 ± 0.00 ^a	30.33 ± 15.17 ^a
G-Ac	10.23 ± 11.70 ^{cd}	5.12 ± 4.43 ^a	12.93 ± 7.88 ^a
G-Jiq	8.33 ± 10.40 ^{cd}	1.66 ± 2.88 ^a	19.33 ± 7.37 ^a
G-Tab	6.56 ± 6.50 ^{cd}	6.66 ± 6.66 ^a	21.00 ± 8.71 ^a
G-LR	0.00 ± 0.00 ^d	4.44 ± 3.84 ^a	15.07 ± 13.79 ^a

^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].

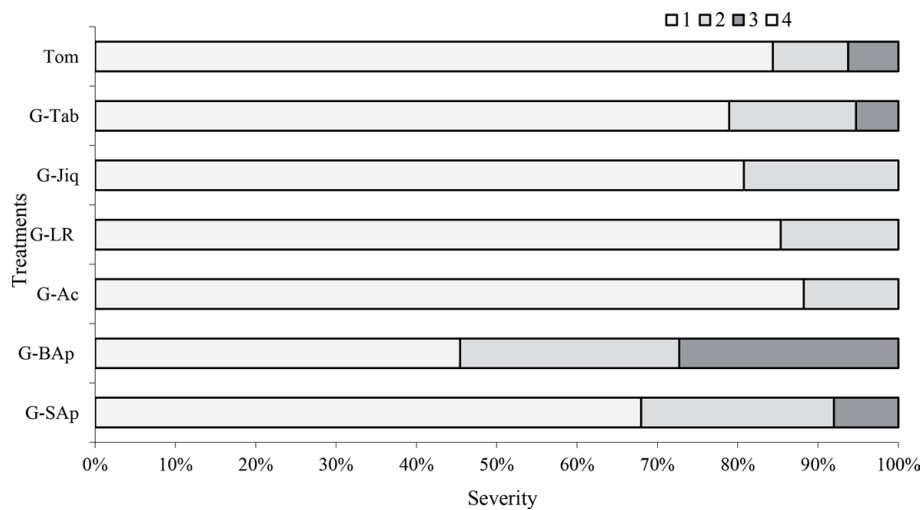


Figure 1.
Distribution of severity levels of Geminiviridae in different epidemics of tomato grafting under field conditions in Paracuaro, Michoacan: 1 = no damage, 2 = start of damage, 3 = medium damage, 4 = total damage [53].

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 <i>Fusarium</i>
	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.

* 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).

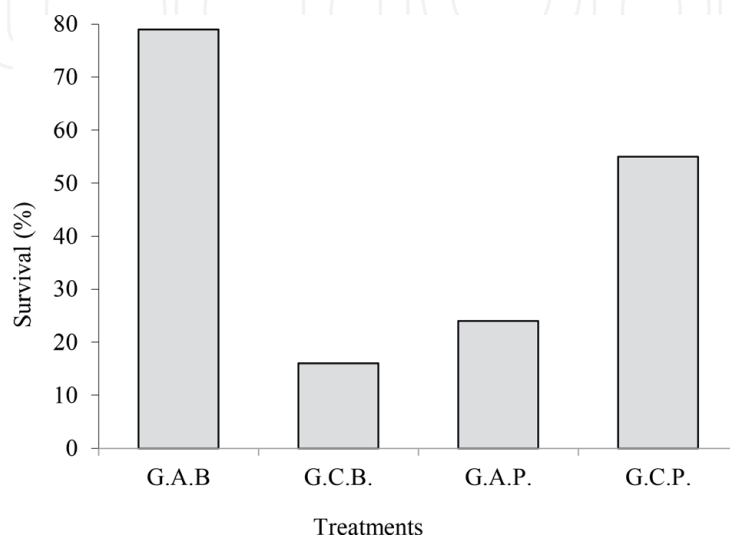


Figure 2. Methods of approach and cleft graft and two fixation devices [68].

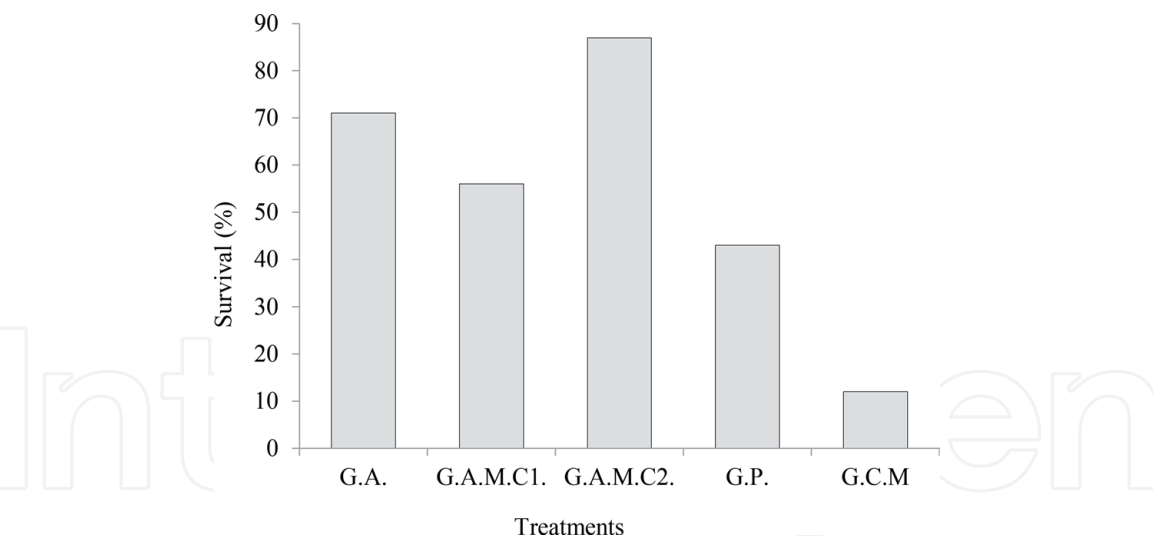


Figure 3.
Modified approach and cleft graft methods and two fixation devices [68].

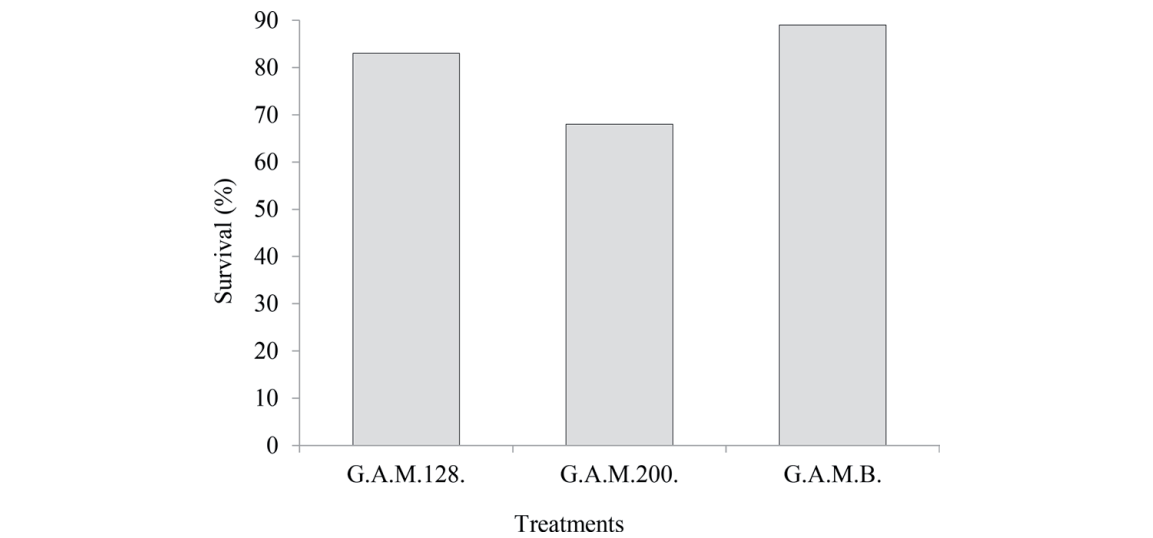


Figure 4.
Modified graft method in different containers [68].

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

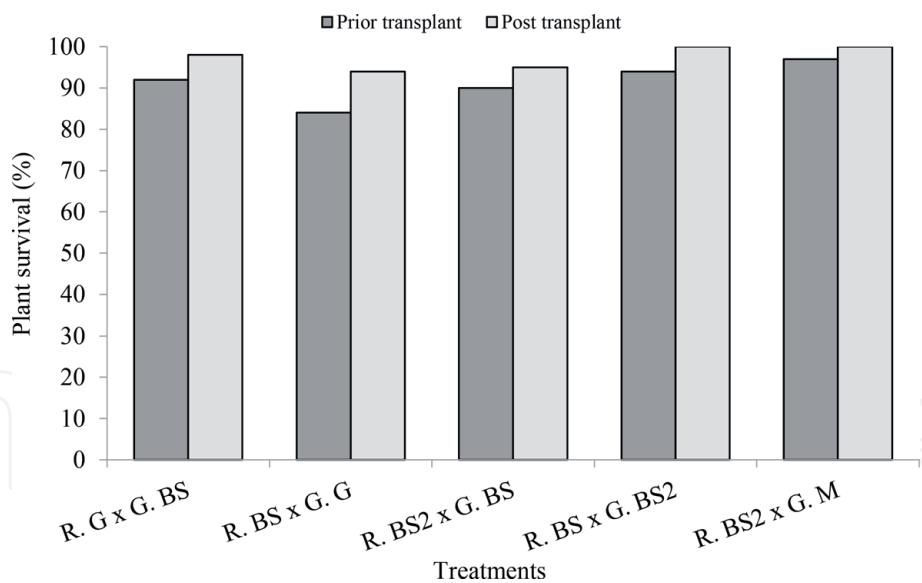


Figure 5.
Quality of grafted papaya plant prior and post transplant.

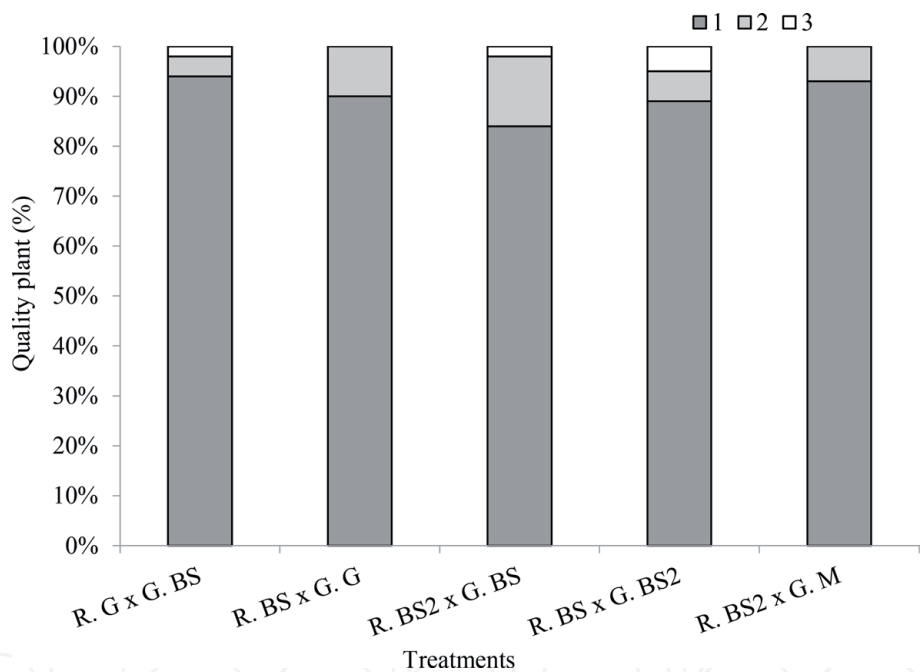


Figure 6.
Quality level of grafted papaya plant [69].

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 \times G. BS, R. BS \times G. G., and R. BS2 \times 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 \times G. G. and R. BS2 \times 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 \times G. G., and R. BS2 \times 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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