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Article

Economic analysis of whitefly management in tomato cultivation

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Abstract

Husk tomato (*Physalis ixocarpa* Brot.) is an important crop in Mexico whose profitability is affected by pests; therefore, it is necessary to evaluate management alternatives that improve yield and reduce losses. The research was conducted in 2023 to evaluate the efficacy of chemical and natural plant protection products, applied individually and in combination with a plant extract (Aza-Direct®1.2 CE), on fruit yield and profitability. Sixteen treatments were evaluated under a completely randomized block design with three replications (48 experimental units per trial). Each unit consisted of three 4 m-long furrows, 0.95 m apart, with plants spaced 0.4 m apart. The insecticides were applied 16 days after transplantation on three occasions, with seven-day intervals. Yield evaluation was performed up to 105 days after transplantation. An Anova and a Tukey test (## 0.05) were performed using the SAS statistical software. The experiment was replicated twice. In experiment 1, the Minecto Duo®, Benevia®and Toretto®treatments, in combination with azadirachtin, showed yield increases of 48.8%, 46.7% and 32.7%, respectively, compared to the control without application. In experiment 2, Minecto Duo®with azadirachtin showed the highest increase, reaching 96.2% compared to the control. In the absence of the plant extract, the largest increases were recorded with Benevia®(88.5%) in experiment 2 and with Minecto Duo®(27.2%) in experiment 1. All treatments were economically viable, with return-on-investment ratios greater than $1.50.

Keywords:

Bemisia tabaci, Physalis ixocarpa, profitability.

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Introduction

In Mexico, vegetable production represents an activity of great economic and social importance, with the state of Sinaloa standing out as one of the largest producing regions; among the most relevant horticultural crops is husk tomato (*Physalis ixocarpa* Brot.), valued for its characteristic flavor, nutritional contribution, and wide use in traditional Mexican gastronomy (Peña-Lomelí *et al* ., 2014 ; SIAP, 2024).

This crop has a wide national distribution, with a presence in 28 states, an estimated per capita consumption of 3.5 kg (SIAP, 2018), and yields exceeding 60 t ha^{-1}(Castro-Brindis *et al* ., 2000). Nonetheless, despite its productive and economic importance, the adoption of sustainable agricultural practices remains limited, as the area allocated to organic management barely reaches 120 ha nationwide (Rivadeneyra-Manzanilla *et al* ., 2024).

The profitability of the husk tomato crop is influenced by multiple factors, including production costs, agronomic management, access to appropriate technologies and phytosanitary control (Díaz-Nájera *et al* ., 2025); in particular, efficiency in the use of irrigation water and the implementation of integrated pest management are essential to maximize yield and reduce operating costs (Martínez-Carrillo *et al* ., 2009 ; Espinosa-Castañeda *et al* ., 2018).

However, producers face various challenges, such as the constant increase in the prices of agricultural inputs, climatic variability, the incidence of pests and diseases, as well as the low technification in some production systems (Cervantes-Godoy and Dewbre, 2010), factors that limit the competitiveness of the crop and compromise its long-term sustainability (Cruz-Delgado *et al* ., 2013 ; Rahman *et al* ., 2022).

Economic analysis is an essential tool for estimating key profitability indicators, such as the break-even point, return on investment, and benefit-cost ratio (Rendón-Medel *et al* ., 2012); this type of evaluation allows comparing different production schemes, such as conventional and organic, based on their technical efficiency and financial viability (Terrones-Cordero and Sánchez-Torres, 2011).

In this context, the study aimed to evaluate the efficacy of chemical and biological plant protection products, applied individually and in mixture with a plant extract (Aza-Direct®1.2 CE), on fruit yield and profitability.

Materials and methods

Study area

The research was conducted in November 2023 in the irrigation unit of the municipality of Huitzuco de los Figueroa, Guerrero, located at 18° 29’ north latitude and 99° 05’ west longitude with respect to the Greenwich meridian, at an altitude of 940 m. The region is characterized by a warm sub-humid climate with rainfall concentrated in summer. The average annual temperature and the average minimum and maximum temperatures are 23 °C, 12 °C, and 36 °C, respectively, with an average annual rainfall of 1 000 mm (Nájera and Campos, 2021).

Plant material and agronomic management

The experiment was conducted in duplicate under open field conditions using seedlings of the Siqueiros F1 husk tomato hybrid. The substrate used was forest mulch, which was sterilized by boiling in an aluminum steamer pot with 20 L of water. Subsequently, a mixture (3:1) was prepared with 120 kg of sterilized mulch and 40 kg of Peat Moss®(organic substrate). The seedling trays were disinfected by immersing them for 10 s in a solution of 5 L of commercial sodium hypochlorite (NaClO) (5% Cloralex®) diluted in 200 L of water.

For the preventive control of diseases during the seedling stage, the seeds were treated with Rhizobac®Combi (a consortium of beneficial rhizospheric bacteria, mainly *Bacillus* spp. and

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Pseudomonas spp.) and Rhizo®TX Innovak (*Trichoderma* spp.) at a dose of 1 g 1 $L^{-1}$of water. Land preparation included plowing at a depth of 0.3 m carried out with a tractor, followed by harrowing and furrowing with a separation between furrows of 0.95 m.

A drip irrigation system equipped with a venturi head was installed, allowing the suction and application of fertilizers through the irrigation water (Table 1). The water came by gravity from the Atopula dam, located in the community of Huitzuco de los Figueroa, Guerrero, and was delivered through a 5.08 cm hose to the irrigation tapes, which had a flow rate of 9.25 L $s^{-1}ha^{-1}$.

Table 1. Fertilization is applied by the irrigation system.

Number	Fertilizer	Formula	Dose ha^{-1}
1	Fertiter®P	08-24-02	2 L
2	Yara Tera®Calcinit	$5Ca(NO_3)NH_4NO_310H_2O$ (calcium nitrate)	12 kg
3	NutriPeak®	18-18-18+EM	30 kg
4	Despegue®Plus	08-25-05	12 L
5	Yara Tera®Urea	46-00-00	12 kg
6	Auxigro®	Gamma-aminobutyric and glutamic acids	350 g
7	HarvestMore®	10-55-10	2.5 kg

Experimental design and unit

Sixteen treatments were evaluated, which were distributed in a randomized complete block design with three replications, resulting in a total of 48 experimental units; two experiments were performed at the same time and in the same location (Table 1). Each experimental unit consisted of three 4 m-long rows, 0.95 m apart, with a distance of 0.4 m between plants, totaling 30 plants per unit in 11.4 m^2.

To estimate the yield, eight plants were selected in the center row of each experimental unit (useful plot), ensuring full competition between them. The treatments were applied preventively on three occasions at 16 (DAT), with seven-day intervals; the product doses used were those presented in Table 2, which were dissolved in 2.5 L of water per treatment for the three replications of each experiment.

Table 2. Treatments with chemical and biological insecticides, with and without azadirachtin, evaluated in husk tomatoes.

Symbology	Azadirachtin	Treatment/ / product	Active ingredient	Dose ha^{-1}
T1	With Azadirachtin	Aza-Direct®1.2 CE	Azadirachtin (3%)	2 000 ml
T2		Beleaf®	Flonicamid (50%)	200 g
T3		Muralla maxx®	Imidacloprid (19.6%) + beta-cyfluthrin (8.4%)	200 ml
T4		Sivanto®Prime	Flupyradifurone (17.09%)	750 ml
T5		Minecto duo®	Thiamethoxam (20%) + cyantraniliprole (20%)	500 g
T6		Toretto®	Sulfoxaflor (21.8%)	400 ml
T7		Benevia®	Cyantraniliprole (10.26%)	400 ml
T8		Eday®	*Verticillium lecanii* (21 x 10^6conidia g^{-1})	100 g
T9	Without Azadirachtin	Control	Without insecticide protection	0
T10		Beleaf®	Flonicamid (50%)	200 g

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Symbology	Azadirachtin	Treatment/ / product	Active ingredient	Dose ha^{-1}
T11		Muralla maxx®	Imidacloprid (19.6%) + beta-cyfluthrin (8.4%)	200 ml
T12		Sivanto®Prime	Flupyradifurone (17.09%)	750 ml
T13		Minecto duo®	Thiamethoxam (20%) + cyantraniliprole (20%)	500 g
T14		Toretto®	Sulfoxaflor (21.8%)	400 ml
T15		Benevia®	Cyantraniliprole (10.26%)	400 ml
T16		Eday®	*Verticillium lecanii* (21 x 10^6conidia g^{-1})	100 g

Study variable

Fruit yield

Three harvests were evaluated, selecting eight plants from the central row with full competence for yield measurement.

Economic analysis

The evaluation was carried out to determine the profitability of the treatments studied, calculating the following economic indicators according to the methodology proposed by Durán (2006) ; Krugman and Wells (2006); Samuelson and Nordhaus (2009). Total cost (TC)= sum of fixed and variable costs (TC= FC + VC). Total income (TI)= calculated as the income generated by the sale of the fruit, using the formula TI= Py × Y. Where: Py= is the price of the product; and Y= is production per ha. Net income (NI)= result of subtracting the total cost from the total income (NI= TI-TC). Profit per peso invested (PPI)= obtained by dividing net income by total cost (PPI= NI/TC) (Perdomo-Moreno, 2001 ; Muñante, 2002).

Statistical analysis

The data obtained were analyzed by means of an analysis of variance (Anova) using SAS®9.4 (SAS, 2016). For the multiple comparison of means, Tukey's method was applied with a significance level of $\alpha \leq 0.05$.

Results and discussion

Experiment 1

In the three evaluations of fruit weight, no significant differences were found between treatments (P= 0.414^{NS}, 0.3547^{NS}, and 0.2468^{NS}). Plants sprayed only with azadirachtin (T1, Aza-Direct®) showed a reduction in fruit weight of 7.9% and 10.85% compared to the control without treatment with plant extract (T9) in evaluations 1 and 2, respectively; however, in evaluation 3, they outperformed the control by 65.5% (Table 3).

Table 3. Average yield of husk tomato fruit from synthetic and natural insecticide treatments in experiment 1.

Treatment	Azadirachtin	Evaluation (days after transplantation)*	Cumulative total of 3 cuts	Yield			
		1 (62)	2 (76)	3 (89)		(kg EU^{-1})**	(t ha^{-1})
Aza-Direct®1.2 CE	With Azadirachtin	353a	630a	493.7a	1476.7	35.44	38.87
Beleaf®		738.3a	655a	302.3a	1695.6	40.7	44.63

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Treatment	Azadirachtin	Evaluation (days after transplantation)*	Cumulative total of 3 cuts	Yield			
Muralla maxx®		797.3a	735a	396.3a	1928.6	46.29	50.78
Sivanto®Prime		567.3a	421.7a	676.3a	1665.3	39.97	43.82
Minecto duo®		813a	1375a	848.7a	3036.7	49.56	54.35
Toretto®		1211.3a	550a	606.7a	2368	44.18	48.44
Benevia®		1018.3a	945a	1070.3a	3033.6	48.81	53.55
Eday®		766a	846.7a	450a	2062.7	38.71	42.45
Control	Without Azadirachtin	383.3a	706.7a	298.3a	1388.3	33.31	36.52
Beleaf®		775a	993.3a	566.7a	2335	39.99	43.84
Muralla maxx®		702.7a	440a	350a	1492.7	35.81	39.27
Sivanto®Prime		533.3a	816.7a	513a	1863	39.84	43.66
Minecto duo®		539a	851.7a	700a	2090.7	42.39	46.45
Toretto®		636.7a	623.3a	251.7a	1511.7	36.3	39.77
Benevia®		692.3a	683.3a	393.7a	1769.3	41.19	45.13
Eday®		886.7a	623.3a	663.7a	2173.4	38.57	42.26
Prob F		0.414^{NS}	0.3547^{NS}	0.2468^{NS}			
MSD		1035.3	1140.4	1005.3			

*= kg plant^{-1}; MSD= minimum significant difference. Values with equal letters within columns are not statistically different (Tukey, α< 0.05).

On the other hand, chemical and biological insecticide treatments combined with Aza-Direct®(T2 to T8) showed variable effects; in particular, plants protected with Toretto®(T6), Minecto Duo®(T5), and Benevia®(T7) recorded fruit yield increases of 243.1%, 118.3%, and 116.8% in evaluations 1, 2 and 3, respectively, compared to plants treated only with azadirachtin (T1); nevertheless, these differences were not statistically significant.

Similarly, treatments applied without combination with Aza-Direct®(T10 to T16) also showed variable results; for instance, fruit weight in plants treated with Eday®(T16) was 151.18% and 34.43% higher in evaluations 1 and 3, respectively, compared to the individual Azadirachtin treatment (T1); however, in evaluation 2, Beleaf®(T10) outperformed Eday®(T16) by 59.36%. It should be noted that none of these differences reached statistical significance (Table 3).

Regarding the average cumulative yield (t ha^{-1}), the plants protected only with Aza-Direct®presented a yield 6.43% lower than the control (T9). On the other hand, chemical and biological treatments, both applied with and without azadirachtin, achieved yield increases of 48.8% and 27.2%, respectively (Table 3).

Experiment 2

In this experiment, as in the previous one, the treatments did not show statistically significant differences in terms of fruit weight, P= 0.1486^{NS}, 0.8839^{NS}and 0.3763^{NS}(Table 3). The effect of the treatment with azadirachtin applied individually (T1, Aza-Direct®) was variable; in evaluations 1 and 2, the plants presented an increase in fruit yield of 16.7% and 95.3%, respectively, compared to the control (T9); nevertheless, in evaluation 3, this treatment exceeded the yield obtained with the plant extract by 59.3% (Table 4).

DOI: https://doi.org/10.29312/remexca.v17i4.4063

Table 4. Average yield of husk tomato fruit from synthetic and natural insecticide treatments in experiment 2.

Treatment	Azadirachtin	Evaluation (days after transplantation)*	Cumulative total of 3 cuts	Yield			
		1 (62)	2 (76)	3 (89)		(kg UE^{-1})**	(t ha^{-1})
Aza-Direct®1.2 CE	With application	575ab	686.7a	198.7a	1460.4	360	39.5
Beleaf®		516ab	511.7a	542a	1569.7	38.7	42.4
Muralla maxx®		535.7ab	746.7a	352.3a	1634.7	40.3	44.2
Sivanto®Prime		713.3ab	571.7a	302.7a	1587.7	39.1	42.9
Minecto duo®		1033.7a	720a	527.7a	2281.4	56.2	61.6
Toretto®		838.3ab	450a	835a	2123.3	52.3	57.4
Benevia®		626.3ab	480a	819.3a	1925.6	52.3	29
Eday®		678.7ab	443.3a	407.3a	1529.3	47.5	52.1
Control	Without application	492.7ab	351.7a	316.7a	1161.1	28.6	31.4
Beleaf®		672ab	450a	728a	1850	45.6	50
Muralla maxx®		602.3ab	473.3a	674a	1749.6	43.1	47.3
Sivanto®Prime		539ab	625a	710.7a	1874.7	46.2	50.7
Minecto duo®		690ab	251.7a	494.3a	1436	35.4	38.8
Toretto®		612.3ab	615a	300.7a	1528	37.7	41.4
Benevia®		616.7ab	671.7a	902a	2190.4	54	59.2
Eday®		348.3b	676.7a	335.7a	1360.7	33.5	36.8
Prob F		0.1486^{NS}	0.8839^{NS}	0.3763^{NS}			
MSD		648.65	990.19	1108.6			

*= kg plant^{-1}; MSD= minimum significant difference. Values with equal letters within columns are not statistically different (Tukey, α< 0.05).

On the other hand, chemical treatments combined with Aza-Direct®(T2-T8) also showed inconsistent results; in evaluations 1 and 2, plants treated with the insecticide Minecto Duo®(T5) increased fruit yield by 79.8% and 4.8%, respectively, compared to *Azadirachtin* applied individually (T1). Nonetheless, in evaluation 3, the weight of fruits harvested from plants protected with Benevia®(T7) was 55.25% higher than that of fruits from plants treated with Minecto Duo®(Table 4). It should be noted that these differences were not statistically significant.

In addition, when chemical and biological treatments were applied without combining them with the plant extract (Aza-Direct®), the results were also inconsistent. The largest average increases in fruit yield were observed in plants protected with Benevia®(T15), Sivanto®Prime (T12) and Beleaf®(T10), with increases of 88.6%, 61.4% and 59.3%, respectively, compared to the absolute control (T9), which received no protection at all. Nevertheless, these variations were not statistically significant either (Table 4).

Finally, in terms of the average cumulative yield in tonnes, a 24.2% increase was observed in the plants protected with Aza-Direct®compared to the control (T9). Likewise, chemical and biological treatments applied with azadirachtin and without this plant extract showed increases of 53.2% and 83.2%, respectively (Table 4).

In the trial on chemical control of whitefly conducted by Tiwari (2020) , it was determined that the application of neem extract in interaction with the chemical insecticide cyantraniliprole increased fruit weight in tomato crops by 30%, due to the improvement in plant health and fresh product quality.

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Economic analysis of treatments

The structure of production costs and the economic indicators obtained in experiments 1 and 2 (Table 5) show that the activities that represent the greatest investment are sowing (15.29%) and harvesting and marketing (39.84%). These results confirm that manual harvesting is one of the most expensive stages in cultivation, a situation that repeats itself in other vegetables; in this sense, Camacho-Luna (2005) reported that the cost of harvesting zucchini ranged from 8.1% to 19.01% of the total investment made.

Table 5. Cost structure of a husk tomato production system in \$ ha^{-1} of the 2023-2024 cycle in experiments 1 and 2.

Item	Experiment 1		Experiment 2	
	Amount (\$)	(%)	Amount (\$)	(%)
Land use	10 000.00	6.45	10 000.00	6.45
Land preparation	17 104.00	10.25	17 104.00	11.02
Sowing	23 721.50	15.29	23 721.50	15.29
Soil nutrition	9 336.00	6.02	9 336.00	6.02
Transplantation	2 500.00	1.61	2 500.00	1.61
Foliar and root nutrition	14 540.00	9.37	14 540.00	9.37
Control of (unevaluated) pests	1 905.00	1.23	1 905.00	1.23
Disease control	927.00	0.6	927.00	0.6
Control of evaluated pests	13 285.00	8.56	13 285.00	8.56
Harvesting and marketing	61 800.00	39.84	61 800.00	39.84
Total cost (TC)	155 118.50	100	155 118.50	100
Total income (TI) from husk tomato	507 364.98		426 086.58	
Net income (NI= TI-TC)	352 246.48		270 968.08	
Profit per peso invested: PPI= NI/TC	2.27		1.75	

The economic results of experiments 1 and 2 demonstrated the profitability of the crop under different treatments, with profit-per-investment (PPI) ratios above \$1.50 in both cases. All the treatments evaluated were profitable, since for each peso invested in the production process, profits of \$2.27 and \$1.75 were obtained in experiments 1 and 2, respectively. On the other hand, Camacho-Luna (2005) reported that the cost of harvesting zucchini ranges from 8.1% to 19.01% of the total investment made in this crop. Zoilo *et al* . (2018) and Orona-Castillo *et al* . (2023) note that other aspects to be considered in economic indicators include production costs and sales prices in order to determine profits.

Finally, Rucoba-García *et al* . (2006) conducted a profitability analysis of a tomato production system under greenhouse in the central-south region of Chihuahua and reported that, according to the analysis carried out, the main variables that can help the company to increase its profitability are variable costs and production volume, since their modification depends directly on the company and in its ability to search for raw materials at a lower cost and increase their volume through better crop management and the introduction of varieties with higher yields.

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Conclusions

The insecticide treatments Minecto Duo®, Benevia®, and Eday®, combined with the plant extract Aza-Direct®1.2 CE (*Azadirachtin*), as well as the individual treatments with Benevia®, Beleaf®, and Eday®, showed a significant effect on the increase in fruit yield per plant, evidencing their effectiveness in the phytosanitary management of the husk tomato crop.

Timely, technically based agronomic management was confirmed as a key factor in improving crop yield, quality and profitability, as it directly affects the effective reduction of pests and diseases. The economic analyses conducted in experiments 1 and 2 demonstrated the financial viability of the treatments applied, as profit-per-investment rates exceeding 1 were obtained in all cases, indicating a positive return on investment.

The precise implementation of agricultural practices, supported by rigorous technical-economic analysis, enables greater efficiency in input use, contributes to the sustainability of the production system and strengthens decision-making in integrated crop management.

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