Mexican Journal of Phytopathology
ISSN: 2007-8080

Crossref
Open access

Scientific Article

Estimation of losses caused by *Potato virus Y* in potato crop in Coahuila

Joel De Santiago-Meza*, Gustavo Alberto Frías-Treviño, Luis Alberto Aguirre-Uribe, Alberto Flores-Olivas, Departamento de Parasitología Agrícola, Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila, CP 25315, México.

***Corresponding Author**:
Joel De Santiago-Meza
joelsantiago1797@outlook.com

Section:
Periodical Issue

Received:
05 April, 2024
Accepted:
15 December, 2024
Published:
30 December, 2024
Early Access 2025

Citation:
De Santiago-Meza J, Frías-Treviño GA, Aguirre-Uribe LA and Flores-Olivas A. 2025. Estimation of losses cause by *Potato virus Y* in potato crop in Coahuila. Mexican Journal of Phytopathology 43(1): 48. https://doi.org/10.18781/R.MEX.FIT.2404-2

ABSTRACT

Background/Objective. The objective was to experimentally evaluate the losses caused by PVY in the Fianna variety potato crop and, consequently, estimate the losses caused by this virus in the potato-producing area of Coahuila.

Materials and Methods. Furrows of an experimental plot planted with potato seedling and seed-tuber, were mechanically inoculated with PVY at 20, 40, 60 and 80 days after emergence. The tubers produced were harvested and losses in each treatment were evaluated. Additionally, in four commercial potato fields in this same state, leaflet samples were taken at 20, 40, 60 and 80 days after the emergence, and the percentage of plants infected with PVY was evaluated by ELISA tests. Loss data from the experimental plot and incidence data from the farms were used to develop a statistical model to estimate losses caused by PVY in the Coahuila region.

Results. Yield losses due to PVY in the experimental plot were 9.4% to 53%. The percentage of incidence of infected plants in commercial properties varied from 0% to 100%. The model that best fit the data obtained was Berger's $Y = 1/\left[1 + e\left(-\left\{ln\left[\frac{yo}{1-y0}\right] + r * dae\right\}\right)\right]$. The estimated losses in the Coahuila region in the 2022 cycle were 18%, equivalent to $19 068500. Conclusión: This information highlights the importance of using certified PVY-free seed and protecting the crop from emergence until 60 DAE.

Key words: Epidemiology, viruses, diagnostic, serology

Introduction

Potato virus Y (PVY) is the type species of the *Potyvirus* genus, one of the genera in the Potyviridae family, which includes some of the most destructive plant viruses (Kerlan, 2006; Scholthof *et al*., 2011; ICTV, 2022). PVY ranks fifth among the ten most important plant viruses worldwide (Scholthof *et al*., 2011) and is considered the most economically significant and devastating viral disease affecting potato crops (*Solanum tuberosum*) (Shukla *et al*., 1998; Singh *et al*., 2008; Gray *et al*., 2010; Karasev and Gray, 2013; Quenouille *et al*., 2013).

This virus has been a persistent issue in potato production (Lacroix *et al*., 2010; Kostiw, 2011), as it affects commercial production crops and is among the three most critical diseases in seed potato production (NOM-041-FITO-2002). High PVY incidence levels have been responsible for the disqualification of seed lots for certification, leading to a significant reduction in crop value and, in some cases, a shortage of certified seed (Gray *et al*., 2010).

In Mexico, the use of certified seed tubers for potato production is a phytosanitary requirement established by the Official Mexican Standards NOM-040-FITO-2002 and NOM-041-FITO-2002. However, the yield benefits of using certified seed free of rapidly spreading viruses, such as PVY, have not been evaluated. Additionally, there are no reports estimating yield and economic losses caused by this virus in the potato-producing region of Coahuila. Consequently, the objectives of this research were: 1) to experimentally evaluate the losses caused by PVY in *Fianna* potato plants; and 2) to estimate the yield and economic losses caused by PVY in the potato-producing region of Coahuila.

Materials and Methods

Study Sites. The experimental plot used to evaluate losses caused by PVY in 2022 was located at the "El Bajío" Experimental Field of the Universidad Autónoma Agraria Antonio Narro (UAAAN), situated at 25° 21' 21" N and 101° 02' 26" W. The field was plowed and furrowed with an 80 cm spacing between furrows and a bed width of 80 cm. Additionally, during the same year, foliage samples were collected from four commercial *Fianna* potato fields, conventionally managed by their owners. These production fields were located in the Emiliano Zapata and Huachichil ejidos in Arteaga, Coahuila, at 25° 06' 00" N and 100° 45' 14" W and 25° 12' 15" N and 100° 47' 34" W, respectively.

PVY Diagnostic Method. Two PVY diagnostic methods were used, both based on the antigen-antibody reaction: the ImmunoStrips® method (AGDIA, 2023) and the double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) method (Engvall and Perlmann, 1971).

Obtaining propagative material. During the 2021 potato harvest in the production regions of Coahuila and Nuevo León, Mexico, 250 *Fianna* tubers were collected. The tubers were kept under laboratory conditions until two sprouts, 2 to 7 cm in length, developed on each. Composite samples were formed by mixing five sprouts from different tubers, and the presence or absence of PVY was determined in each composite sample using ImmunoStrips® (AGDIA, 2023). The tubers were classified based on the results: those testing positive for PVY and those without the virus. Two groups were then formed from this classification. Each group included both PVY-positive and PVY-negative tubers. The first group was designated for seedling production, while the second was used as seed tubers. The tubers intended for seedling production were planted in 5 kg polyethylene bags under greenhouse conditions (22 to 26 °C) and covered with insect-proof netting. Fifteen days after plant germination, foliage samples (three leaflets per plant) were collected and individually diagnosed for PVY using the DAS-ELISA method with AGDIA kits. PVY-infected plants were kept separate from healthy plants until field transplantation (Trial 1). Tubers used as seed were individually tested for PVY using the same method applied to seedlings. PVY-infected tubers were separated from healthy ones and later planted at the “El Bajío” Experimental Field (Trial 2).

Experimental design

Assay 1 - Seedling Transplantation. At *El Bajío*, eight furrows were prepared, each measuring 1.40 m in length and 80 cm in width, with 80 cm spacing between them. Four furrows were planted with potato seedlings naturally infected with PVY, while the other four were planted with healthy seedlings. Each furrow contained seven plants as the experimental unit, totaling 56 plants for the trial. A completely randomized design was implemented with two treatments (healthy and infected plants) and four replicates. To prevent disease transmission between treatments, the furrows were covered with insect-proof netting supported by wire frames at a height of 1.4 m. To ensure that the PVY-free plants remained healthy throughout the experiment, composite samples of seven young leaflets per plant were collected from this treatment before harvest (120 days after emergence) and analyzed using the DAS-ELISA method.

Assay 2 – Direct Sowing. In the same experimental plot as Assay 1, seed tubers were sown in seven furrows, each measuring 5 m in length and 80 cm in width, with 80 cm spacing between them. A completely randomized design was used with six treatments and four replicates. Each replicate consisted of five plants as the experimental unit, totaling 120 plants for the experiment. The treatments were as follows: tubers naturally infected with PVY, healthy tubers (control), and plants inoculated with PVY at 20, 40, 60, and 80 days after emergence (20 plants per inoculation). To prevent virus dissemination between treatments, the furrows were covered with insect-proof netting, identical to that described in Assay 1.

Inoculum preparation and inoculation. Four replicates of five plants each were inoculated at 20, 40, 60, and 80 days after emergence (DAE). Three grams of PVY-infected foliar tissue, collected from diseased plants in Assay 1, were weighed and placed in a previously sterilized and cooled mortar. Then, 30 mL of phosphate buffer solution (prepared with sodium phosphate monobasic monohydrate and sodium phosphate dibasic heptahydrate) at a pH of 8.0 were added in a ratio of 1 g of tissue per 10 mL of buffer. The tissue was ground using a previously sterilized and cooled pestle. The sap was filtered using sterilized gauze into a container kept on ice throughout the procedure, and 0.0340 grams of diatomaceous earth (Celite®) were added as an abrasive. Using a pestle, the sap was gently rubbed onto three of the youngest leaflets of each healthy plant, starting at the base of the leaf and moving toward the tip while avoiding excessive pressure. Immediately after inoculation, the inoculated tissue was sprayed with phosphate buffer solution (pH 8.0) until runoff occurred.

Two weeks after each inoculation, the youngest leaflet from each inoculated plant and from the control plants was collected and processed using the ImmunoStrip® method (AGDIA, 2023) to confirm successful inoculation and to verify that the control plants remained virus-free. The inoculated plants were individually diagnosed by mixing three of their youngest leaflets into a single sample for processing. In the control group, plants were diagnosed using composite samples formed by mixing five young leaflets, one from each plant.

Commercial plots. The incidence percentage of PVY was determined in four commercial plots of *Fianna* potato located in the potato-producing region of Coahuila: Emiliano Zapata (50 ha), San Felipe (40 ha), La Mesa (50 ha), and Huachichil (60 ha). Foliar sampling and DAS-ELISA tests were conducted. Four samplings were performed in each plot at 20, 40, 60, and 80 days after plant emergence (DAE), aligning with the inoculation times specified for the experimental plot in Assay 2. Each sampling followed the guidelines of NOM-041-FITO-2002, with a modification in sample size. Five random sites were selected in each plot, and 40 young leaflets (one per plant) were collected at each site, resulting in a total of 200 leaflets per plot. The collected leaflets were placed in polyethylene bags, labeled, and stored in insulated containers to prevent deterioration and contamination, maintaining a temperature between 5–12 °C. In the laboratory, composite samples of ten leaflets each were formed and processed.

Evaluation of Losses

Assay 1 - Transplantation. The furrows transplanted with seedlings were harvested 130 days after transplantation. The tubers from each treatment were cleaned to remove soil residues, weighed using a digital scale, and their yield recorded. To estimate yield per hectare, the average yield in kilograms per plant was calculated and multiplied by 55,556 (the planting density for the region). Losses caused by PVY were determined by comparing the yields of each treatment with the control. Plant and tuber size were not evaluated in this assay.

Assay 2 – Direct sowing. The furrows sown with seed tubers were harvested 130 days after planting. The procedure previously described in Assay 1 was repeated to determine yield. Losses caused by PVY were calculated for the experimental plot when infected seed tubers were used and when plants were inoculated at 20, 40, 60, and 80 days after emergence (DAE). Loss data were plotted against infection dates and statistically analyzed to select the model that best described the relationship between these variables. The loss models evaluated included the Exponential, Power Law, and Berger models (Campbell and Madden, 1990). Additionally, tuber quality was assessed following the *Norm for Ware Potatoes* (FAO, 2020). Using a vernier caliper, tubers from each treatment were measured and classified by category according to equatorial diameter: first quality (>80 mm), second quality (25–80 mm), and third quality (18–24 mm). Tuber counts were recorded for each category.

Commercial plots. Based on the results of the DAS-ELISA tests for each plot and sampling date, the incidence percentage was calculated. Yield losses in each commercial plot were estimated using the model fitted to the loss vs. infection date data from the experimental plot. The incidence from each sampling in each plot was used to estimate the number of diseased plants, which were then assigned the respective yields observed in Assay 2 of the experimental plot. For example, the total number of plants estimated to be positive at 20 DAE was multiplied by the average yield of plants inoculated at the same age in the experimental plot. This procedure was repeated for the other treatments. These data were extrapolated to the total hectares planted with *Fianna* potatoes to estimate yield losses caused by PVY in the state of Coahuila.

Results and Discussion

Assay 1 - Transplantation. The yield in furrows transplanted with infected seedlings was 0.4 kg/plant, lower than the 0.57 kg/plant observed in furrows transplanted with healthy seedlings. Based on these data, the yield per hectare was 22.22 t for seedlings derived from infected seed tubers and 31.66 t for those from healthy seed tubers (Figure 1). Using this information, it was calculated that the yield loss due to secondary PVY infections in transplanted plants within the experimental plot was 30%. Although plant and tuber size were not evaluated in this assay, all furrows showed reduced growth in PVY-infected plants (Figure 2). These infected plants produced fewer and smaller tubers compared to virus-free plants.

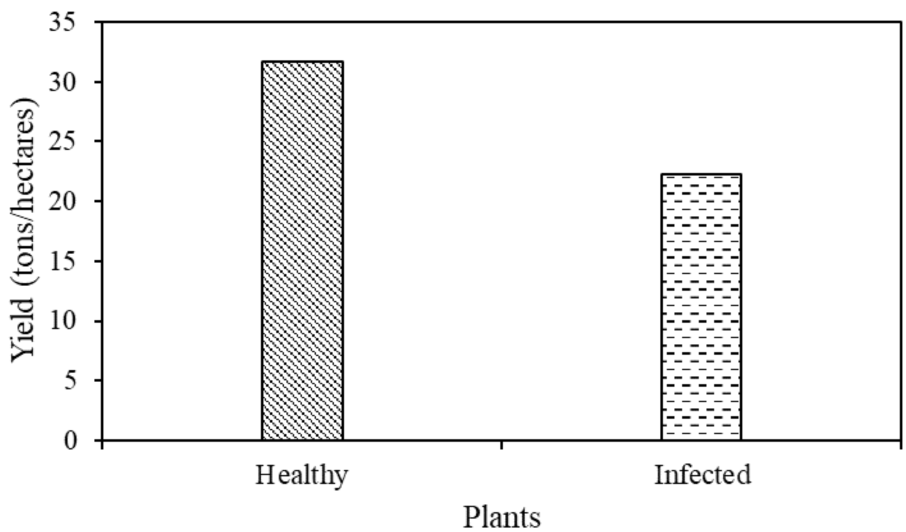

Figure 1. Yield per hectare of Fianna potato plants in Assay 1.

Figure 2. Left: plants grown from tuber seed infected with PVY; right: plants grown from PVY-free tuber seed.

Assay 2 – Direct sowing. The yield of plants grown from PVY-infected seed tubers was 0.55 kg/plant, significantly lower than the 1.17 kg/plant recorded for healthy plants. Based on these results, the yield per hectare was 30.72 t for infected seed tubers and 64.84 t for healthy seed tubers (Figure 3). Using these data, it was calculated that the yield loss due to secondary PVY infections in the experimental plot was 53% (Figure 4). Plants developed from PVY-infected seed tubers produced

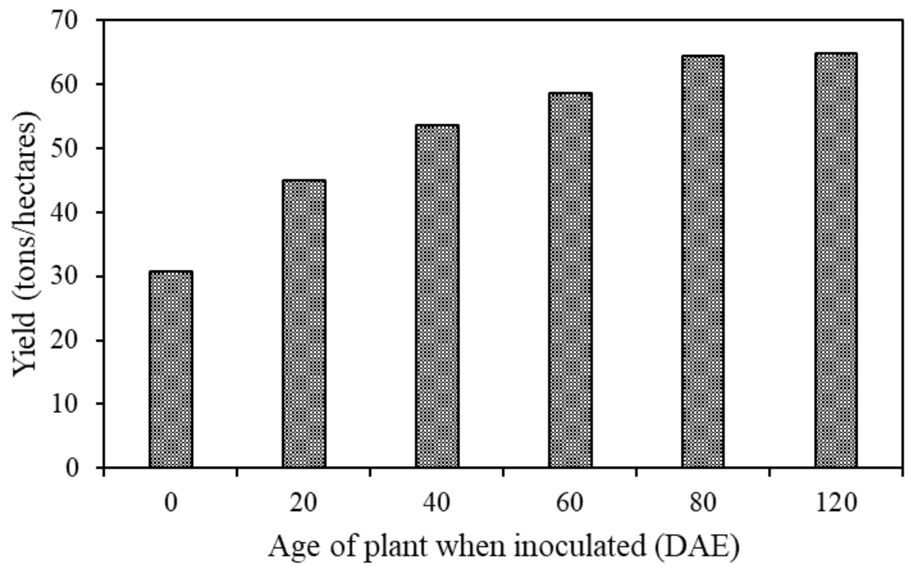

Figure 3. Yield per hectare of plants grown from infected tuber seed (0), plants inoculated at 20, 40, 60, and 80 DAE, and healthy plants (remained healthy throughout the 120-day cycle).

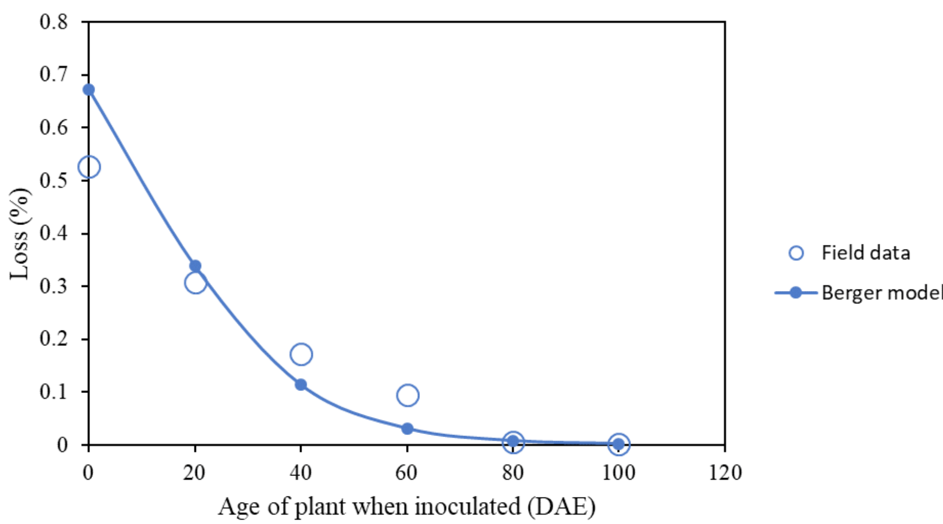

Figure 4. Fit of the Berger model explaining 98% of the variation in losses relative to the date of PVY infection (days after emergence - DAE).

fewer tubers of lower quality compared to healthy plants. The number of "first quality" and "second quality" tubers was higher in healthy plants than in infected ones (Figures 5 and 6).

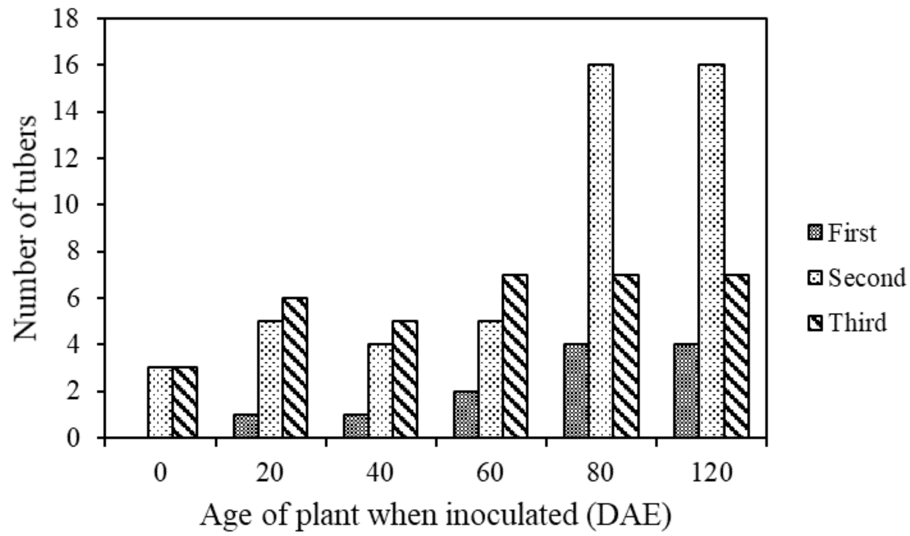

Figure 5. Quantity and quality of tubers produced by plants grown from infected tuber seed (0), plants inoculated at 20, 40, 60, and 80 days after emergence (DAE), and healthy plants.

Plants inoculated at 20, 40, 60, and 80 days after emergence (DAE) yielded 0.81, 0.97, 1.06, and 1.16 kg/plant, respectively. Correspondingly, the calculated yield per hectare for these inoculation times was 44.88, 53.65, 58.68, and 64.44 t (Figure 3). These results indicate that primary PVY infections caused yield losses of 30.7%, 17.3%, 9.5%, and 0.61%, depending on the timing of inoculation (Figure 4). Plants inoculated at 20, 40, and 60 DAE produced higher-quality tubers than those grown from infected seed tubers, including "first quality" tubers and a greater number of "second quality" and "third quality" tubers. However, both the quantity and quality of tubers from plants inoculated at these earlier times were lower than those of plants inoculated at 80 DAE and healthy plants (Figures 5 and 6).

A decrease in yield losses was observed as the age of the plant at the time of PVY infection increased. Using this relationship between the age of the plant at infection and yield loss, it was determined that the model that best describes this relationship is the Berger model: $Y = 1/\left[1 + e\left(-\left\{ln\left[\frac{yo}{1 - y0}\right] + r * dae\right\}\right)\right]$ (Figure 4). This conclusion is supported by the coefficient of determination (R^2) and the high significance of the regression when applying this model.

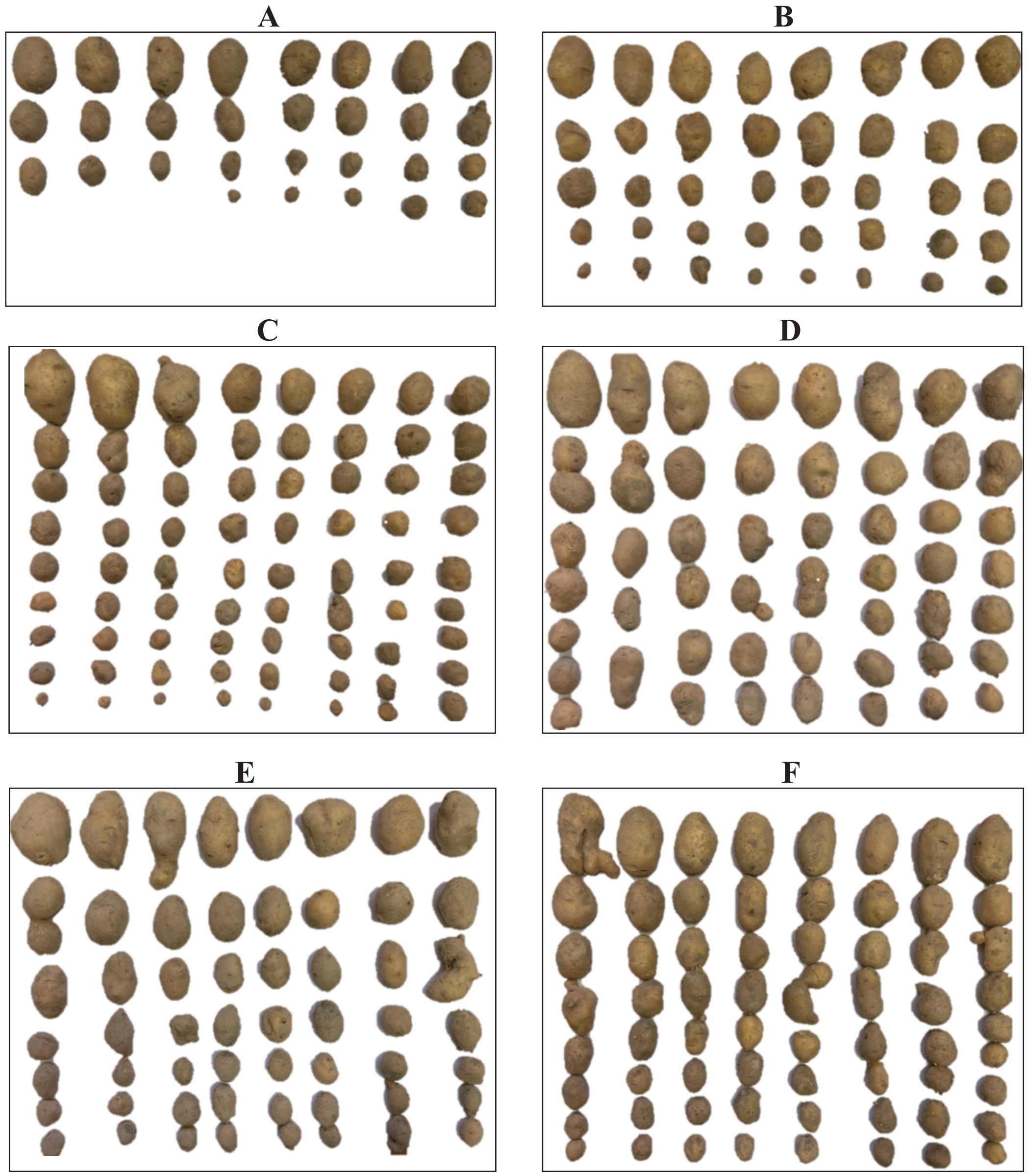

Figure 6. Tubers produced by: A) plants grown from infected tuber seed; B) plants inoculated at 20 DAE; C) plants inoculated at 40 DAE; D) plants inoculated at 60 DAE; E) plants inoculated at 80 DAE; F) healthy plants (no inoculation).

Estimation of losses in commercial plots. The percentage of infected plants in the commercial plots ranged from 0% to 100% across the four samplings. In Emiliano Zapata, the incidence was 100% in the first three samplings and 92% in the fourth. In San Felipe and La Mesa, the percentages were 100% and 5%, respectively. No presence of PVY was detected in Huachichil (Table 1).

Table 1. Percentage of infected plants in commercial fields; ha = hectares, No. Samples = number of samples per field, DAE = days after emergence, No. Leaflets = number of leaflets.

Field	ha	No. Samples	DAE	No. Leaflets	Incidence (%)
Emiliano Zapata	50	4	20	200	100
			40	200	100
			60	200	100
			80	200	92.5
San Felipe	50	4	20	200	100
			40	200	100
			60	200	100
			80	200	100
La mesa	40	4	20	200	5
			40	200	5
			60	200	5
			80	200	5
Huachichil	60	4	20	200	0
			40	200	0
			60	200	0
			80	200	0

Using the loss estimation model $Y = 1/[1 + e\ (-\{ln[0.67205626] + - 0.0694 * dae\})]$, developed with data from the two experimental plot assays and the percentage of infected plants at various crop ages in the commercial plots, yield and economic losses were estimated for the potato-producing region of Coahuila (Table 2). Considering that the sampled area (200 plants) represents 77% of the total area planted with the *Fianna* variety in the state and using the average price per ton of $10,000 (SIAP, 2022), it was estimated that the state-wide yield loss is 18%. This corresponds to an economic loss of $19,068,500 for the state.

Table 2. Estimated yield and economic losses in the potato-producing region of Coahuila.

Field	Losses (tons/hectares)	Losses (tons/field)	Economic losses ($)
E. Zapata	20	1 000	10 000 000
San Felipe	20	800	8 000 000
La Mesa	2.3	107	1 068 500
Huachichil	0	0	0
Total		**1 907**	**19 068 500**

Losses from primary infections. The yield of plants inoculated at 20, 40, and 60 DAE was lower compared to those inoculated at 80 DAE and the control (healthy plants), with the latter two showing similar yields. This could be attributed to the limited time available for the virus to replicate and disrupt the plant's physiological system, resulting in no significant reduction in productivity. Hernández (2006) reported yield reductions of 28.5% and 20.7% when inoculating *Atlantic* potato plants at 20 and 60 DAE under greenhouse conditions. A similar pattern was observed in this study, where plants inoculated at 20 and 60 DAE exhibited yield reductions of 30.7% and 9.5%, respectively.

Losses from secondary infections. Secondary PVY infections transmitted through seed tubers caused yield losses of 30% and 53% compared to plants grown from virus-free seed tubers. These findings align with those reported by Hane and Hamm (1999), who found total yield reductions of 29% to 79% depending on the potato variety. Similarly, they are consistent with the study by Whitworth et al. (2006), which reported total yield reductions ranging from 38% to 63%, influenced by soil nitrogen levels and potato variety. The results highlight the critical importance of seed tuber condition in potato production. Yield was significantly lower when seed tubers were infected compared to virus-free tubers. Thus, one of the most effective ways to avoid yield losses is to plant certified virus-free seed tubers. Certification programs should also implement stricter regulations to prevent the sale of contaminated seed tubers. These findings support the conclusions of Gray et al. (2010) and Vreugdenhil et al. (2007), who emphasized that PVY is one of the main contributors to reduced potato yield and quality. In the United States, PVY has also led to a shortage of certified virus-free seed tubers due to the rejection of contaminated lots, resulting in a significant decrease in crop value (Gray et al., 2010).

Tuber quantity and quality. Plants infected through seed tubers produced fewer and smaller tubers compared to those grown from virus-free seed tubers. Similarly, plants inoculated at 20, 40, and 60 days after emergence (DAE) showed lower tuber yield and quality than plants inoculated at 80 DAE and those from healthy seed tubers. These findings align with the reports of Bokx (1980), Salazar (1995), Vreugdenhil et al. (2007), and Nolte et al. (2009), who noted that PVY disrupts the plant's physiological processes at an early stage, impairing photosynthesis and carbohydrate accumulation. This results in stunted plant growth and reduced tuber production. Yield losses caused by PVY in the two experimental plot assays ranged from 9.4% to 53%, consistent with previous reports. Authors such as Beczner et al. (1984), Hane and Hamm (1999), Pérez et al. (2004), Salazar (1995), Whitworth et al. (2006), and Zuñiga et al. (1999) have reported that PVY-related losses in potato crops vary between 10% and 80%, depending on the cultivar, viral strain characteristics, storage conditions, environmental factors, and the management of insect pests and weeds.

Estimation of losses in Coahuila. The commercial fields with the highest percentage of infected plants were San Felipe and Emiliano Zapata. In these fields, an incidence rate of 100% was recorded during the sampling conducted 20 DAE. It is noteworthy that seeds from the same distributor were used, but they were different from those planted in La Mesa and Huachichil, where lower incidence rates were recorded. This information suggests the hypothesis that the seeds were infected at the time of planting, as no rapid dissemination mechanisms were observed to explain subsequent infections. In the yellow traps set up by producers, no aphids were detected, and the plants did not yet have enough foliage to allow for mechanical virus transmission. It is recommended to conduct sampling before purchasing seeds and to send these samples to a laboratory authorized by SENASICA to rule out or confirm the aforementioned hypothesis. This action could prevent producers—and consequently the region—from suffering economic losses due to reduced crop yieldThe economic losses estimated in this study differ from those reported by McIntosh (2014), who calculated that PVY has a direct economic impact of $19.56 million (approximately $326,213,027) in the state of Idaho. On the other hand, they are similar to the results of Dupuis et al. (2023), who reported yield losses of 23.5% for the most commonly cultivated varieties in Switzerland between 2004 and 2017. It is important to highlight that the incidence percentage in their study was visually assessed through symptoms caused by secondary PVY infections, a procedure not considered viable because some varieties may harbor low concentrations of the virus without exhibiting symptoms (Singh, 1998). A similar situation might have occurred in this study, given that the methods used require a high viral load in the plant to detect the pathogen. However, these tools are more cost-effective considering the number of samples obtained, and they provide rapid data to assess the phytosanitary conditions of a region.

Conclusions

Yield losses caused by PVY in Fianna potato crops in the experimental plot ranged from 9.4% to 53%, while the estimated losses in the Coahuila region during the 2022 cycle were 18%, representing an economic loss of $19,068,500 for the state. These results highlight the importance of using certified PVY-free seed and protecting the crop from emergence to 60 DAE, with a particular emphasis on the first weeks. Additionally, this provides the basis for designing a more informed strategy to efficiently manage the disease and reduce the losses it causes.

Acknowledgments

To CONAHCYT, Unidad de Inspección Fitosanitaria SERVESA A.C., the producers, and everyone who contributed to this research.

References

AGDIA. 2023. ImmunoStrip® for Potato virus Y (PVY). https://orders.agdia.com/agdia-immunostrip-for-pvy-20001 (consulta, enero 2024).

Beczner L, Horváth J, Romhanyi I & Förster H. 1984. Studies on the etiology of tuber necrotic ringspot disease in potato. Potato Research, 27, 339-352. https://link.springer.com/article/10.1007/BF02357646

Bokx JA. 1980. Virosis de la papa y de la semilla de papa (1a. ed.). Buenos Aires, hemisferio sur.

Campbell CL and Madden LV. 1990. Introduction to plant disease epidemiology. Jonh Wiley & Sons, Nueva York, 532 pp.

Dupuis B, Nkuriyingoma P and Ballmer T. 2023. Economic Impact of Potato Virus Y (PVY) in Europe. Patata Res. 67, 55-72. https://doi.org/10.1007/s11540-023-09623-x

Engvall E and Perlmann P. 1971. Enzyme-linked immunosorbent assay (ELISA) quantitative assay of immunoglobulin G. Immunochemistry, 8(9), 871-874. https://doi.org/10.1016/0019-2791(71)90454-x.

FAO-Organización de las Naciones Unidas para la Alimentación y la Agricultura. 2020. Codex Alimentarius; Normas Internacionales de los Alimentos. Norma Para la Patata (Papa) de Consumo CXS 339-2020. 6 pp. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B339-2020%252FCXS_339s.pdf (consulta, enero 2024)

Gray S, De Boer S, Lorenzen J, Karasev AV, Whitworth J, Nolte P, Singh R, Boucher A and Xu HM. 2010. Potato virus Y: An evolving concern for potato crops in the United States and Canada. Plant Dis. 94 (12):1384-1397. https://doi.org/10.1094/PDIS-02-10-0124

Hane D and Hamm P. 1999. Effects of seedborne potato virus Y infection in two potato cultivars expressing mild disease symptoms. Plant Dis. 83:43-45. https://doi.org/10.1094/PDIS.1999.83.1.43

Hernández D. 2006. Actividad Virustatica de Viprot l y Viprot ll, sobre Potato Virus Y (PVY) de la Papa en Invernadero. Tesis de Licenciatura. Universidad Autónoma Agraria Antonio Narro. 52 pp. http://www.repositorio.uaaan.mx:8080/xmlui/handle/123456789/4253

ICTV - International Committee on Taxonomy of Viruses. Master Species List. 2022. https://ictv.global/ (consulta, febrero 2024)

Karasev AV and Gray SM. 2013. Continuous and emerging challenges of Potato virus Y in potato. Annual review of phytopathology, 51, 571-586. https://doi.org/10.1146/annurev-phyto-082712-102332

Kerlan C. 2006. Potato virus Y. AAB/CMI Descriptions of Plant Viruses 414. https://hal.science/hal-02817093v1

Kostiw M. 2011. The occurrence of major potato viruses in Poland. Journal of Plant Protection Research. https://doi.org/10.2478/v10045-011-0035-7

Lacroix C, Glais L, Kerlan C, Verrier JL and Jacquot E. 2010. Biological characterization of French Potato virus Y (PVY) isolates collected from PVY-susceptible or-resistant tobacco plants possessing the recessive resistance gene va. Plant pathology, 59(6), 1133-1143. https://doi.org/10.1111/j.1365-3059.2010.02342.x

McIntosh C. 2014. The economics of PVY. In: Uo I. Idaho Potato Conferences. University of Idaho Extension.

Nolte P, Alvarez JM and Whitworth JL. 2009. Potato virus Y management for the seed potato producer. University of Idaho Extension CIS1165. http://www.potatogrower.com/uploads/7266_1.pdf

NOM 040 FITO 2002. Requisitos y especificaciones para la producción y movilización nacional de papa comercial. Diario Oficial de la Federación, 21 de febrero del 2003. https://www.gob.mx/senasica/documentos/normas-oficiales-mexicanas-en-materia-de-sanidad-vegetal (consulta, enero 2024).

NOM 041 FITO 2002. Requisitos y especificaciones fitosanitarios para la producción de material propagativo asexual de papa. Diario Oficial de la Federación, 4 de marzo del 2003. https://www.gob.mx/senasica/documentos/normas-oficiales-mexicanas-en-materia-de-sanidad-vegetal (consulta, enero 2024).

Pérez L, Rico E, Sánchez JR, Ascencio JT, Díaz R and Rivera RF. 2004. Identificación de Virus Fitopatógenos en Cultivos Hortícolas de Importancia Económica en el Estado de Guanajuato, México. Revista Mexicana de Fitopatología, 22 (2),187-197. https://www.redalyc.org/pdf/612/61222205.pdf

Quenouille J, Vassilakos N and Moury B. 2013. Potato virus Y: a major crop pathogen that has provided major insights into the evolution of viral pathogenicity. Molecular plant pathology, 14(5), 439-452. https://doi.org/10.1111/mpp.12024

Salazar LF. 1995. Los virus de la papa y su control. Centro Internacional de la Papa. p. 256. https://books.google.com.mx/books/about/Los_virus_de_la_papa_y_su_control.html?id=LARBgjJWi4QC&redir_esc=y

Scholthof KB, Adkins S, Czosnek H, Palukaitis P, Jacquot E, Hohn T, Hohn B, Saunders K, Candresse T, Ahlquist P, Hemenway C and Foster GD. 2011. Top 10 plant viruses in molecular plant pathology. Molecular plant pathology, 12(9), 938–954. https://doi.org/10.1111/j.1364-3703.2011.00752.x

Shukla DD, Ward CW and Brunt AA. 1998. Description of plant viruses 366. https://doi.org/10.1007/3-540-31042-8_147

SIAP-Servicio de Información Agroalimentaria y Pesquera. 2022. https://www.gob.mx/siap/acciones-y-programas/produccion-agricola-33119 (consulta, junio 2023).

Singh RP. 1998. Reverse-transcription polymerase chain reaction for the detection of viruses from plants and aphids. Journal of Virological Methods 74:125-138. https://doi.org/10.1016/S0166-0934(98)00074-3

Singh RP, Valkonen JP, Gray SM, Boonham N, Jones RAC, Kerlan C and Schubert J. 2008. Discussion paper: The naming of Potato virus Y strains infecting potato. Archives of virology, 153, 1-13. https://link.springer.com/article/10.1007/s00705-007-1059-1

Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Taylor MA, MacKerron DKL and Ross HA. 2007. Potato biology and biotechnology advances and perspectives. Elsevier. Italy. 801 p. https://books.google.com.mx/books?hl=es&lr=&id=H9WWTORVS9kC&oi=fnd&pg=PP1&dq=Vreugdenhil,+D.,+Bradshaw,+J.,+Gebhardt,+C.,+Govers,+F.,+Taylor,+M.+A.,+MacKerron,+D.+K.+L.,+Ross,+H.+A.+2007.+Potato+biology+and+biotechnology+advances+and+perspectives.+Elsevier.+Italy.+801+p.&ots=3Y_VjVsIny&sig=Q4R6SlizfoVhwBnCnFjfBF_8pNM#v=onepage&q&f=false

Whitworth JL, Nolte P, McIntosh C and Davidson R. 2006. Effect of Potato virus Y on yield of three potato cultivars grown under different nitrogen levels. Plant Disease, 90 (1), 73-76. https://doi.org/10.1094/PD-90-0073

Zúñiga LN, Cadena MA, Molina JD and Rivera A. 1999. Resistencia genética a los virus X y Y (PVX y PVY) de la papa. Agrociencia, 33(4), 389-396. https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/1624