Risk factors associated with the use and management of pesticides in the production of nopal (*Opuntia ficus-indica* (L.) Mill)

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ABSTRACT

Objective: To verify the risk factors associated with the use of agrochemicals, through the degree of compliance with Mexican regulations on the Good Use and Management of Pesticides (BUMP).

Design/Methodology/Approach: One-hundred producers, selected from a group of 300 producers who make up the register of the Sistema Producto Nopal in Morelos, Mexico, answered the questionnaire. The questionnaire included plot information, market data, and open questions about the compliance with the checklist for the recognition of areas where Good Use and Management of Pesticides (BUMP) standards are applied in the primary production of vegetables of the National Service of Health, Food Safety and Agro Food Quality (SENASICA)

Results: Out of all the one-hundred producers surveyed, 57 were recognized in BUMP and 43 were not. Whether producers complied or not with these regulations and could have access to the export market depended on the crop area and the economic income it represents. The greatest non-compliance was caused by the non-authorized use of pesticides in the production of nopal, which represents a contamination risk for the worker, the environment, and the consumers.

Study Limitations/Implications: Studies should be carried out about the impact on the health of farm workers and the environment resulting from the inappropriate use of pesticides.

Findings/Conclusions: Although the implementation of BUMP in the nopal cultivation minimized the risks of contamination or poisoning, the non-authorized use of synthetic pesticides for its cultivation poses contamination risks to the worker, consumer, and environment. Therefore, strategies must be generated in the domestic market to guarantee the same food safety than in the international market.

Keywords: BUMP, chemical contamination, pesticides, Opuntia ficus-indica.

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INTRODUCTION

The economic and social importance of nopal (*Opuntia ficus-indica* (L.) Mill) cultivation in Mexico lies in the exportation volume (61,387 t among 15 countries), in the large area occupied by *nopaleras* (both wild and cultivated nopal fields), and in the diversity of nopal-

based products produced and consumed in the country (Badii and Flores, 2001; Maki-Díaz *et al.*, 2015; SIAP, 2022). In the state of Morelos, nopal is grown in a total area of 4,217 hectares, distributed in the municipalities of Tlalnepantla (3,030 hectares), Totolapan (554 hectares), Tlayacapan (512 hectares), and Tepoztlán (61 hectares); consequently, Morelos is the main nopal producer in Mexico (SIAP, 2021).

Nopal plantations, like other agricultural systems, are attacked by different pests and diseases, and the most common management method is chemical control (Pérez *et al.*, 2013). However, improper handling and application of pesticides can entail risks for humans, either as a user or consumer (Fenik *et al.*, 2011). In the last two decades, poisoning incidence from the consumption of vegetables has increased considerably due to the presence of chemical contaminants (Johnston *et al.*, 2006; Tzschoppe *et al.*, 2012). In addition, the environmental impact panorama is critical (Albert, 1996). Therefore, in developing countries such as Mexico, training activities on the safe handling of pesticides have been carried out during the said period, with the aim of making farmers aware of the harmful effects of these products; nevertheless, a significant change in attitude has not been achieved yet and sometimes this awareness cannot be put into practice (Damalas *et al.*, 2006; García, 1999; Isin and Yildirim, 2007). Consequently, government initiatives have been developed and implemented, such as production models based on "Good Agricultural Practices" and "Food Safety" (Pérez *et al.*, 2013). The National Service of Health, Food Safety and Agro Food Quality (SENASICA) promoted, through the Comité Estatal de Sanidad Vegetal del Estado de Morelos, A.C, the implementation of practices for the Good Use and Management of Pesticides (BUMP) among 94 local producers who operate 146 production units in over 185 ha, with the purpose of reducing the risk of chemical contamination in nopal production (SAGARPA, 2020).

Therefore, the objective of this work was to verify the risk factors associated with the use of agrochemicals in the production units that belong to the producers included in the register of the Sistema Producto Nopal in Morelos.

MATERIALS AND METHODS

Study area

The nopal producing region in Morelos is comprised of representative areas of the municipalities of Tlalnepantla, Tlayacapan, and Totolapan. This region is located in the northwest of the state of Morelos (Figure 1); it has a subhumid climate, an average annual rainfall between 913 and 2,341 mm, and an average annual temperature of 17 °C.

Study population

These municipalities have a total population of 40,101 inhabitants, with a similar sex ratio and an average elementary education of 63.7% (INEGI, 2020) (Table 1).

In Tlalnepantla, 90% of the population grows nopal as their primary crop, because it generates a high level of income, mainly in autumn and winter, when it is scarce in other producing states (Rubio, 1997), while, in Totolapan and Tlayacapan, the activity of nopal is shared with other vegetables.

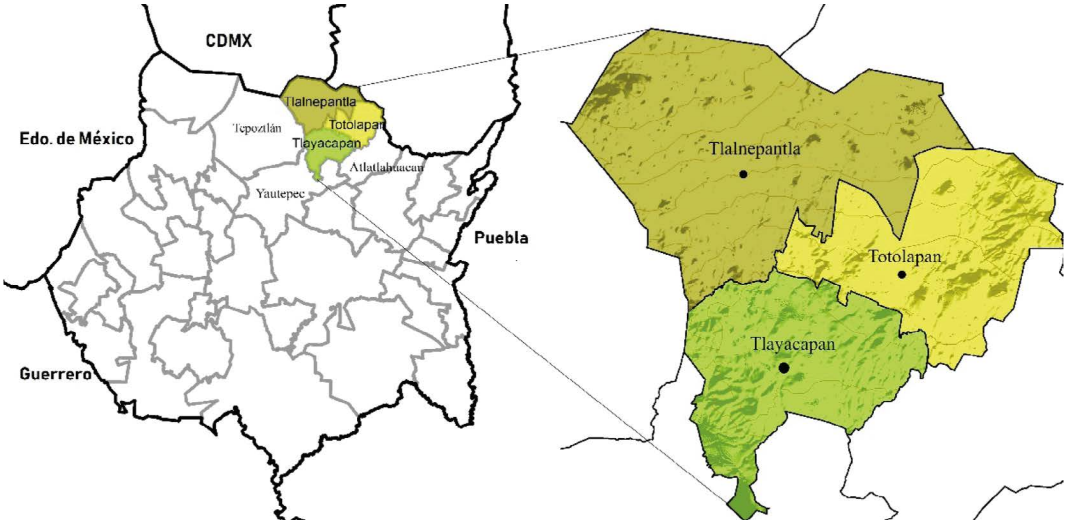

Figure 1. Geographic location of the nopal producing region in Morelos, Mexico.

Table 1. Population characteristics of the nopal producing region in Morelos.

Municipality	Population	Men (%)	Women (%)	Primary education (%)*
Tlayacapan	19,408	49.6	50.4	55.0
Tlalnepantla	7,943	50.1	49.9	69.9
Totolapan	12,750	48.6	51.4	66.3

Source: INEGI, 2020. * People 15 years or older with primary school education.

The register of the Sistema Producto Nopal producers of Morelos was taken as a basis for this study. The simple random sampling method was applied to develop a sample of 100 of the 300 producers that make up the total register.

Questionnaire

The questionnaire was designed as a tool for a descriptive, transversal, and observational process; it involved the voluntary participation and signed consent of the interviewees. The questionnaire included plot information, market data, and open questions about the compliance with the checklist for the recognition of areas where Good Use and Management of Pesticides (BUMP) standards are applied in the primary production of vegetables of the National Service of Health, Food Safety and Agro Food Quality.

Forty-one questions were distributed in eight sections: general information, infrastructure, use and management of pesticides, agrochemical products, personal protective equipment and spraying equipment, preparation of mixtures of agrochemical products, disposal of leftover mixtures, and management of empty containers. The plantations, warehouses, and leftover mixture disposal areas were visited to verify the conditions of use and agrochemical management.

RESULTS AND DISCUSSION

Eighty plots located in Tlalnepantla, fifteen in Tlayacapan, and five in Totolapan were verified. Out of the total producers, 57 were recognized by SENASICA in BUMP and 43 were not. Both groups had received training in BUMP. However, the unrecognized group had not invested in infrastructure or the recognition process. They argued that the income per production area is not enough for the required investment (infrastructure and recognition). All the interviewees (100%) were men between 45 and 60 years old, 99% of whom had attended elementary school and only one had a bachelor's degree. None of the participants mentioned the risk of direct chemical contamination to women and children, since they stated that they themselves were in charge of cultivation work in the field, hiring adult male laborers for the cutting.

Infrastructure

With regard to documentary infrastructure, 100% of the recognized producers had a procedures manual that described the control measures that were applied during the handling of agrochemicals. On the matter of personnel hygiene and safety, all producers complied with the provisions of sections 5.12 and 6.8 of NOM-251-SSA1-2009 (SSA, 2009). Regarding physical infrastructure, 80% of the recognized producers established appropriate storage areas for personal protective equipment, disposal of empty containers, and storage of pesticide application equipment; however, upon verification, 5% of these spaces were in disarray and did not receive maintenance. All the producers (100%) implemented an area for the preparation of pesticide mixtures and the disposal of leftover mixtures, following the corresponding requirements, and 93% provided a maintenance plan signed by the person responsible. In addition, they also shared a record of product doses, which included agrochemicals not recommended for the cultivation of nopal. Thirty-eight percent of the unrecognized producers complied with the physical infrastructure, but not with any of the other requirements.

Signage of basic facilities

One-hundred percent of the recognized producers complied with the provisions of NOM-026-STPS-2008 (STPS, 2008) during verification. When asked what the signs referred to and why they were placed in different areas, they correctly interpreted the images, unlike the unrecognized producers who did not have signs.

Storage of agrochemical products, personal protective equipment, and spraying equipment

Ninety-one percent of the recognized producers had a warehouse, where they established spaces for storage, with separation between pesticides and fertilizers. These spaces were built with non-absorbent and non-flammable material; they were ventilated and well-lit. The door was locked and the key was kept by a trained adult in 86% of the cases. Seventy-four percent of the recognized producers stored their pesticide spraying equipment and personal protective equipment (used during the application activities) in safe areas, consequently preventing health and contamination risks in accordance with section

7.2.1 and 7.2.2 of NOM-003-STPS-1999 (STPS, 1999). On the contrary, unrecognized producers usually stored pesticides and spraying equipment in common areas, putting the health of farm workers at risk. In this regard, several authors have documented that inadequate hygiene and safety measures, lack of training in the handling of agrochemicals, and misuse of personal protective equipment are among the main reasons for poisoning among farm workers (Cárdenas *et al.*, 2010; Gómez-Arroyo *et al.*, 2013; Guzmán-Plazola *et al.*, 2016). Ortiz-Hernández *et al.* (2013) point out that the chronic and acute damages from exposure to pesticides are diverse and indisputable: infertility, psychological damage, chromosomal abnormalities, and increased risk of melanoma, leukemia, and cervical cancer (Thrupp, 1991; Wesseling *et al.*, 1996; Cuenca and Ramírez, 2004).

Agrochemical mixture preparation and leftover mixture disposal

One-hundred percent of the producers with BUMP recognition had areas to prepare agrochemicals and to rinse empty containers. These areas are separated from water sources and have a spill containment pit, with a firm floor that ensures the evaporation of the liquid and a structure that prevents the entry of domestic and wild animals. However, 53% of the unrecognized producers did not have such areas and prepared the agrochemical mixtures in 200-L drums; subsequently, they overspray the leftover mixtures on the edges of the crop and rinse the drums in the area where the mixtures were prepared, potentially polluting soils and water sources through runoff or infiltration. In this regard, Hernández-Antonio and Hansen (2011) studied the pesticide content in water samples from two agricultural areas of Mexico, finding that the concentrations of the atrazine (4.62-15.01 μg L^{-1}) herbicide exceeded the permissible limits for water for human consumption proposed by the World Health Organization (2 μg L^{-1}) and the European Community (0.1 μg L^{-1}), posing a risk to human health.

Use and management of pesticides

All the producers interviewed were trained on the use and management of pesticides. Although they used synthetic pesticides registered before the Federal Commission for the Protection against Sanitary Risks (COFEPRIS, 2017), the use of these pesticides was not authorized for nopal cultivation. However, producers ignored the recommendations on the labels, arguing that no products have been authorized for nopal cultivation. In this sense, although Montoya *et al.* (2013) point out that the agricultural producer must comply with laws, standards, and techniques regarding the handling of agrochemicals, Hernández-González *et al.* (2007) argued that the lack of training on the correct interpretation of the product label encourages its inappropriate use. Lack of knowledge about the safety intervals of the products used could harm the health of both workers and consumers.

Handling of empty containers

One-hundred percent of the producers with BUMP recognition reported having been technically trained to manage empty containers and they had a temporary collection area for triple-washed and perforated containers. In addition, they showed documentary evidence of having previously sent containers to authorized collection centers. These practices contrasted with the management carried out by unrecognized producers. In this regard, SAGARPA (2012) points out that in Mexico approximately 50 million containers of agrochemicals are generated per year (6,020 tons). Their irresponsible handling means that they end up in irrigation canals, rivers, streams, ditches, and the open field, etc., generating sources of environmental pollution and sometimes poisoning problems. Likewise, García-Gutiérrez and Rodríguez-Meza (2012) point out that the disposal of empty containers is a serious problem resulting from agriculture and represents a high risk to environmental and human health. Overall, producers who did not have recognition by SENASICA failed to comply with these regulations. Their argued that the lack of economic resources was the main limitation for the improvement of their infrastructure.

In this study, the recognized producers had an average surface area of 2.7 ha and their production was destined for the export market, while the unrecognized producers had an average surface area of 1 ha and their production was sold in the domestic market. This situation suggests that the larger the area and the export market, the greater the degree of compliance with national regulations. In this regard, the unrecognized producers indicated that the production area did not cover the expenses required to implement the system and that their product is only sold in the domestic market.

This context poses a risk of chemical contamination for the national consumer, who mainly has access to the nopal produced and distributed by farmers who generally do not implement a proper use and management of pesticides. According to Badii and Valera (2008), pesticides provide great benefits to agricultural production and product quality; however, deficient agricultural practices —*e.g.*, respect for safety intervals, good use and management of pesticides, and the correct use of personal protective equipment— are some of the conditions that result in intoxication or poisoning by agrochemicals, either during their application or the consumption of foods that exceed the maximum allowable residue limit. Therefore, greater surveillance and monitoring of good agricultural practices is necessary, in areas of high agricultural activity, to reduce or prevent damage to both the environment and human health.

During the review of the area for the temporary storage of empty containers, 19 active ingredients that had been used in different agricultural practices were identified (Table 2); several of them had different commercial names and their authorization was indeterminate or in force. In all cases, producers do not use authorized pesticides (mainly insecticides); this is an important indicator of the inappropriate use of these products in the nopal cultivation, consequently posing a potential risk of chemical contamination for both producers and consumers, since the application doses and safety intervals of these products are unknown.

Conventional systems are currently characterized by high consumption and dependence on pesticides; therefore, seeking agroecological strategies that minimize negative impacts on the environment and consumers, through lower consumption of agricultural inputs, is a necessary measure. High concentrations of chlorpyrifos, dimethomorph, malathion, omethoate, imidacloprid, and carbendazim has been observed in nopal samples taken

Table 2. List of pesticide active ingredients found in empty containers stored in temporary warehouses of nopal producers in Morelos, Mexico.

Active ingredient	Tox. Cat.	Type of pesticide	Trade name
Abamectin	III	Insecticide/acaricide	Agrimec® 1.8% CE, Agriver® 1.8 CE
Amitraz	IV	Acaricide	Mitoff, Teracix
Benomyl	IV	Fungicide	Promyl 50 P. H.
Carbendazim	IV	Fungicide	Prozycar 500 F
Captan	IV	Fungicide	Captan 50 plus
Chlorothalonil		Fungicide	
Cypermethrin	IV	Insecticide	Cipermetrina 20 CE
Cymoxanil	IV	Fungicide	Curzate 60 DF
Chlorpyrifos	III	Insecticide	Cyren 480, Carioca
Chlorpyrifos+permethrin	III	Insecticide	Disparo, Ventax
Carbofuran	II	Insecticide	Furadan 5 G
Diazinon	IV	Insecticide	Diazinon-bio 25
Fipronil	IV	Insecticide/acaricide	Regent MG-20 GR
Glyphosate	IV	Herbicide	Faena full
Malathion		Insecticide	
Methidathion	III	Insecticide	Suprathion 40 EC
Monocrotophos	II	Insecticide	Zucron, Bazucron 60*, Dicron
Parathion-methyl	III	Insecticide	Foley 2%*
Permethrin	III	Insecticide	Ambush 34 CE*, Matagus 34*

*Tox. Cat. Toxicological category. * Undetermined authorization, ** Registration in force.

from a collection center supplied by producers who do not implement BUMP. These findings contrasted with the nopal samples from BUMP-recognized producers, where no pesticide residues were detected, highlighting the importance of the proper use of these products and the implementation of the BUMP for the protection of both farmers and consumers (Ramírez-Bustos et al., 2018). In this regard, Ramírez-Bustos et al. (2019) studied the dissipation of chlorothalonil, chlorpyrifos, and malathion in the nopal crop, pointing out that the approximate dissipation time for these pesticides is 10 days and their mean life lasts six days. The final concentrations of the three pesticides were below the reference (0.01 mg/kg) Maximum Residue Limits (MRL), suggesting that these products can be safely applied in commercial nopal production at the concentrations established in the said study.

Finally, the federal and state governments must support small-scale producers, who otherwise will not be able to comply with the infrastructure required to implement the Good Use and Management of Pesticides and reduce the risk of chemical contamination among workers, consumers, and the environment. The results of this study provide information to propose and prioritize actions aimed at addressing the problems of small nopal producers in Morelos, along with strict regulation on the use of pesticides. Likewise, comprehensive strategies should be designed and implemented to make production systems accountable for the health of the population and the environment.

CONCLUSIONS

The implementation of the proper use and management of pesticides, established in national regulations, reduces the risks of chemical contamination in the cultivation of nopal. However, the use of unauthorized pesticides for the cultivation of nopal involves risks of contamination to the worker, the consumer, and the environment. Therefore, strategies must be generated in the domestic market to guarantee the same food safety than in the international market. The competent authorities should authorize molecules that provide producers with options for the use of agrochemicals authorized for the control of the pests and diseases detected during the crop cycle.

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