FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

2020

ASSESSMENT OF MYCOTOXINS IN THE CORN VALUE CHAIN IN WESTERN HONDURAS

Final Report

Final Version
July 2020
Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss (PHLIL)

Prepared by
Andréia Bianchini, PhD.
Associate Professor - Food Science & Technology
University of Nebraska-Lincoln

Collaborators

University of Nebraska – Lincoln
Andreia Bianchini, Associate Professor
Luis Sabillón, Assistant Professor of Practice
Rodrigo Mendoza, Research Assistant

Kansas State University
Jagger Harvey, Director, PHLIL
John Leslie, University Distinguished Professor
Dena Bunnel, Assistant Director, PHLIL

Zamorano University
Raul Espinal, Professor

USAID Feed the Future – ACCESS to Markets (MERCADO) Activity
Guillermo Maradiaga, Production Manager

USAID Feed the Future Alliance for the Dry Corridor Activity
Ricardo Lardizabal, Project Director

List of Contents

List of Tables

List of Figures

1. EXECUTIVE SUMMARY

The objective of this report is to outline the multi-sectorial activities carried out in the Feed the Future (FTF) Zone of Influence (ZOI) in Western Honduras. The information included here provides a better understanding of the current situation on grain handling practices with a focus on corn marketers and growers in this region. It also provides information on potential exposure levels to mycotoxin for the population in the area of the study. Finally, it also includes examples on how to improve agricultural practices that may be detrimental to food safety in the region. This study also embarked on country capacity building and training for corn growers, university personnel and students, as well as field technicians. Recommendations on future avenues of research in the country are also outlined. This report is a product of an award provided by the United States Agency for International Development (USAID) Mission in Honduras and co-funding from the USAID Bureau for Food Security. This report is intended to provide USAID/Honduras with proper contextual information for the interpretation of outcomes.

The ZOI is comprised of 131 municipalities in Western Honduras, distributed onto 6 departments: Copán, Intibucá, La Paz, Lempira, Ocotepeque, and Santa Bárbara. Information about production and handling practices for both corn growers and marketers was obtained using a questionnaire. The survey was conducted alongside a collection of corn samples (2.2 Kg/sample) between November 2017 and October 2018. Several practices that may contribute to mycotoxin contamination were observed among those responding to the survey in this study. For example, corn growers reported leaving the corn plants an excessive amount of time after maturity in the field prior to harvesting. This prolonged exposure to the elements enables pests such as rats and birds to damage corn ears, creating entry points for fungi. Once harvested, another observed issue was the insufficient drying time and/or method used. Traditional drying methods, such as sun drying, may lead to inadequate drying, and the problem is compounded by the fact that some growers proceed to store the grain without restricting access to pests (*e.g.,* exposed trojas or tapancos). Furthermore, bags were the preferred method for several marketers and growers, however they are not an effective barrier against insects, fungi, and moisture absorption from the environment. One positive finding was that many corn growers and marketers use metallic silos for storing shelled corn, which do offer protection against spoilage, provided contents are well dried.

Because inadequate handling practices can lead to mycotoxin contamination in corn, an assessment of mycotoxin occurrence in Honduran corn samples was also carried out. Two mycotoxins (aflatoxin and fumonisin) commonly associated with corn were the target of this assessment in the ZOI. In order to achieve this, a sampling design was outlined to collect corn samples intended for human consumption from both rural and urban areas from the departments that are part of the ZOI. The sampling design considered not only the population density but also several of Feed the Future's population-based indicators including poverty, prevalence of underweight women, and stunting, wasting, and underweight in children under 5 years of age. Based on the results obtained, the prevalence of aflatoxin in corn is relatively low in Western Honduras. Detectable levels of aflatoxin were found in 20 percent of the samples, out of which only 7 percent were contaminated above the regulatory limit of 20 µg/Kg established by the U.S. Food and Drug Administration (FDA). At this time, there is no official limit or recommended action level for aflatoxin in Honduras. Fumonisin was substantially more prevalent and widespread in corn samples collected in the ZOI. Among the samples collected, 719 (97 percent) had detectable levels of fumonisin. Of this, every municipality evaluated showed levels exceeding the FDA advisory level of 3 mg/Kg. Currently, no official limit or recommended action level for fumonisin has been defined in Honduras. In addition to aflatoxin and fumonisin, a small-scale study included the evaluation of other fungal toxins. Other mycotoxins detected in the region of study included the *Fusarium* toxins

nivalenol and zearalenone, reaffirming the widespread presence of this mycotoxigenic fungus. Furthermore, numerous samples showed extremely large concentrations of citrinin and diplodiatoxin. Given the co-occurrence of several mycotoxins in Honduran corn, it is possible that these toxins may have detrimental synergistic effects, potentially complicating or aggravating issues associated with chronic diseases. Between 1998 and 2017, Honduras experienced more damage caused by extreme weather events than any other country on earth, ranking first in the German watch Climate Change Vulnerability Index. Extreme rainfall, atypical droughts, variation in the dates of rainfall, loss of fertility and erosion of arable land are all critical problems for agriculture in the country that may continue to exacerbate mycotoxin contamination in the future.

Addressing mycotoxin exposure in the Honduran population may be one of the initial steps towards decreasing the existing constraints to improve human health in the country. This exploratory study revealed mycotoxin contamination in corn harvested, sold and/or consumed in various municipalities throughout Western Honduras. Without help and intervention from government, academia and other organizations, inhabitants of the region will continue to consume contaminated staples to preserve their household food security. To break the unawareness cycle (no awareness; therefore, no action), the first step is education. Inhabitants of the region need to recognize mycotoxins as an addressable food safety risk in order to feel impelled to make changes to their habits. This should include community education for men and women on the health risks associated with mycotoxins and consumption of crops likely contaminated. Additionally, strategies that help address these issues should be disseminated like early prevention strategies that can be applied in the field, proper grain drying and storage, grain selection/sorting, as well as food consumption and preparation habits. Moreover, women can and should have an active and essential role in several of these identified areas, and with proper training and education they can be agents of change in their communities and households to effectively lessen the burden of losses every corn season.

In addition to the mycotoxin assessment in the ZOI in Honduras, the PHL Innovation Lab worked relentlessly to build mycotoxin sampling and analysis capacity in the country. Prior to field sample collection, all field technicians involved in the assessment were trained in proper sample collection and transportation to ensure sample representativeness and integrity. Furthermore, training and technical assistance was provided by PHLIL for the establishment of mycotoxin testing capacity as part of the Food Analysis Laboratory at the University of Zamorano. Hands on training was provided at Zamorano University, as well as at the National University of Honduras (UNAH), to build human capacity in the country. These training opportunities involved the participation of faculty, staff and students from Zamorano University in the mycotoxin assessment, and have created a robust in-country capacity for mycotoxin analysis that could be applied to improve food safety and security in the country. In addition to the workshops, more intensive one-on-one training and technical support was provided by PHLIL researchers to further develop capacity at Zamorano University. This was accomplished by an extended visit to Zamorano University by a member of Dr. Andréia Bianchini's University of Nebraska-Lincoln laboratory team, along with close monitoring of technicians' proficiency through required testing of blinded samples.

The study results alone will not solve the issue; any changes in the current situation in Honduras related to mycotoxin contamination will only be possible if all sectors of the corn value chain become part of the change. Therefore, field technicians were sensitized about the results gathered in this mycotoxin assessment, along with education in the area of agricultural practices that are commonly associated with mycotoxin reduction and/or prevention. With results of the mycotoxin assessment in hand and

empowered by the knowledge of good agricultural and post-harvest practices, the field technicians have become invaluable agents of change in Honduras.

Moving forward, if all sectors involved in this assessment maintain their momentum of generating and spreading knowledge throughout the corn value chain in Honduras, the population of the country will certainly benefit from mycotoxin prevention, as well as improved food and nutritional security, including food safety.

2. ANSWERS TO ASSESSMENT QUESTIONS

This evaluation was designed to answer the key questions established in the Scope of Work (SOW):

- What are the levels of aflatoxin and fumonisin contamination in the corn value chain in Western Honduras?
- What other mycotoxins are present in the corn value chain in Western Honduras?
- Are there certain areas of the ZOI that have higher levels of mycotoxin contamination than other areas?
- What variables, such as location, drying method, length of storage, storage methods, *etc*. affect the presence of mycotoxins?
- Does exposure to mycotoxins vary by gender? In other words, are men and women differentially exposed?
- What are some mitigating measures that could reduce mycotoxin contamination? The mitigating measures should be tailored to the types of mycotoxins present in Western Honduras.
- How does gender (or female empowerment) influence the ability to mitigate exposure to mycotoxins and to adopt technologies and practices for mycotoxin management?

2.1. WHAT ARE THE LEVELS OF AFLATOXIN AND FUMONISIN CONTAMINATION IN THE CORN VALUE CHAIN IN WESTERN HONDURAS?

2.1.1. Background

Mycotoxins are toxic secondary metabolites produced by filamentous fungi as part of their normal life cycle. The consumption of a diet contaminated with mycotoxins is potentially a health hazard for both humans and animals through the induction of acute and chronic effects that may have a teratogenic, oncogenic and immunosuppressive impacts *(1)*. Aflatoxins and fumonisins are mycotoxins of public health and agroeconomic significance that are common contaminants of corn (*Zea mays*) worldwide. Fumonisins are produced by multiple members of the *Fusarium fujikuroi* species complex, especially *F. verticillioides* and *F. proliferatum*, which commonly colonize corn plants and infect the kernels in the field (7). Aflatoxins are produced primarily by *Aspergillus flavus* and *A. parasiticus*, which are generally regarded as storage fungi, although they may thrive in the field and contaminate corn before harvest in dry weather conditions (12).

Acute exposure to high levels of aflatoxin can be fatal, while chronic exposure is associated with impaired growth in children, immunosuppression, and liver cancer around the world (5, 15, 18). Similarly, consumption of fumonisin contaminated corn is associated with esophageal cancer and growth stunting (6, 17). A possible

synergetic interaction from co-exposure to these mycotoxins is known in animal models. For instance, Gelderblomet al. (3) showed that aflatoxin B_1 exposure enhanced the fumonisin B_1 carcinogenic effect in rat liver, whereas McKean et al. (8) reported that fumonisin B_1 increased the acute toxicity of aflatoxin B1 in F344 rats and mosquito fish. In other studies, co-exposure to these mycotoxins led to child growth impairment and an increased chronic liver disease in humans (11, 13). To limit the exposure and toxic effects of mycotoxins in humans and domesticated animals, regulatory agencies have established maximum tolerated levels. The U.S. Food and Drug Administration (FDA) set the regulatory limit for aflatoxin and advisory level for fumonisin in corn intended for human consumption at 20 µg/Kg (20 parts per billion; ppb) and 3 mg/Kg (3 parts per million; ppm), respectively. Likewise, the European Commission (EC) has established maximum limits for aflatoxin (4 ppb) and fumonisin (1 ppm) in corn destined for direct human consumption (2). Currently, there are no official limits or recommended action levels for these mycotoxins in Honduras.

Corn is Honduras' leading crop and the main dietary staple for the country's vast rural and indigenous populations; therefore, both aflatoxin and fumonisin intake through contaminated corn are likely to occur. Mycotoxin dietary intake may be exacerbated in geographic areas affected by adverse climatic conditions and high socioeconomic vulnerability, *e.g.*, the "Dry Corridor" region. This is a climate-fragile and impoverished region that spans Central America's Pacific coast. Previous studies conducted in rural communities in the dry corridor area of Guatemala have identified aflatoxin and fumonisin contamination levels in corn that exceed import limits for the United States and European Union (13, 14). There is an association between the negative health effects observed in children in these rural communities and high levels of exposure to these mycotoxins (10, 13, 16).The Dry Corridor of Honduras is located in the Western and Southern part of the country. It is characterized by prolonged droughts, highly erratic weather patterns, high levels of chronic malnutrition, and a relatively high prevalence of growth retardation amongst children (4). Much of the corn produced in this area is cultivated, harvested and handled through subsistence-oriented agricultural practices that are strongly connected to the region's Mayan-Lenca cultural heritage. Inadequate agricultural practices and poor handling and storage conditions of corn, such as those typically associated with subsistence and self-sufficiency agriculture, may result in the loss of valuable micronutrients and increase exposure to life-threatening fungal toxins. Therefore, it is important to assess the extent of aflatoxin and fumonisin contamination in the corn value chain in Western Honduras to understand factors potentially driving the high incidence of stunted children and under-nutrition in this region.

2.1.2. Evaluation objective(s)

To assess the prevalence of aflatoxin and fumonisin contamination in the corn value chain in western Honduras, taking into consideration Feed the Future indicators of poverty and women/children's nutritional status.

2.1.3. Methodology

2.1.3.1. Study areas and sampling design

Mycotoxin contamination was determined in the corn supply chain of six departments (Copán, Santa Bárbara, Intibucá, La Paz, Lempira, and Ocotepeque) in the Western part of Honduras (Fig. 2.1.1). This geographic area, which falls within Honduras' Dry Corridor, is designated as a Feed the Future Zone of Influence (ZOI).

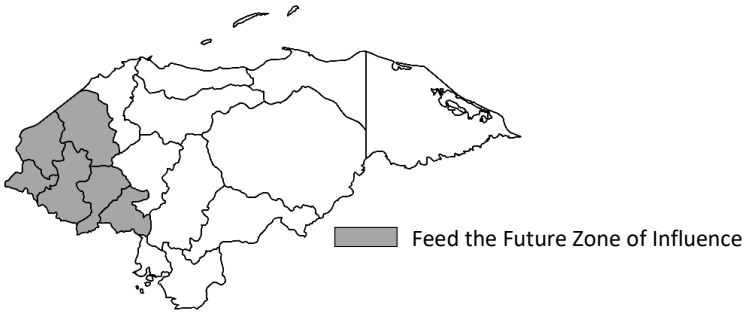


Figure 2.1.1 Map of Honduras showing the region (grey colored area) where the mycotoxin assessment was conducted.

Samples of corn intended for human consumption were collected from both rural and urban areas of the six Feed the Future ZOI departments. The sampling design considered population density and Feed the Future population-based indicators including poverty, *i.e.*, people living on < $1.25/day, the prevalence of underweight non-pregnant women between the ages of 15-49, and indicators associated with underdevelopment in children < 5 years of age, including stunting, wasting, and underweight (4). Stunting in children under the age of five was given a higher weighing as a sample selection criteria. It was considered three times more important than the other indicators when determining the number of samples that should be collected from a specific area. Therefore, although the samples collected in this assessment represent all the ZOI departments, they also favor those municipalities where stunting in children is high. Careful consideration should be taken throughout this document where average, median and ranges of contamination are reported; those are not necessarily values that represent the whole Western region of Honduras, but mostly those locations favored by the criteria used in the sampling design.

The sampling design was devised to include 800 samples that would be distributed among the departments as follows: Copán, 184; Santa Bárbara, 161; Intibucá, 130; La Paz, 105; Lempira, 152; and Ocotepeque, 68. For each department, only municipalities with the poorest indicators, *e.g.*, the highest prevalence of stunting in children, were included in the study (13 from Copán, 11 from Santa Bárbara, 15 from Intibucá, 9 from La Paz, 15 from Lempira, and 8 from Ocotepeque). Samples assigned to each department were further subdivided, based on population density and indicators, between rural and urban area. Therefore, corn sample collection targets

for human consumption were 614 from rural areas (directly from farmers) and 186 from urban areas (from markets). Samples that fit these criteria, when available, were collected. A total of 737 corn samples were collected and analyzed, with 596 originating in rural areas and 141 in urban areas.

In addition to corn intended for human consumption, samples of corn considered of low-quality by smallholder farmers were collected in rural areas. Following the sampling design structure previously described, 135 samples of low-quality corn were collected. Thus, a total of 872 samples of corn were collected and analyzed for mycotoxin contamination in this study. It should be noted that while this report draws conclusions about geographic prevalence of mycotoxins, the episodic and skewed nature of mycotoxin contamination and its reliance on conducive climatic conditions mean that patterns within and between departments can shift depending on the season and year.

2.1.3.2. Collection and storage of corn samples

Corn samples were collected between November 2017 and October 2018. In rural areas of participating municipalities, samples were collected from smallholder farmers who planted and harvested their own corn crops, while in urban locations samples were obtained from wholesale markets and retail stores. Corn samples were composed of freshly harvested corn (<3 days of storage) and corn that had been stored for different lengths of time, ranging from 20 days to 1 year. Storage of samples prior to collection varied and included both conventional, *e.g.*, bags, metal silos, plastic drums, and traditional methods, *e.g.*, trojas, tapancos.

At the point of sample collection, multiple sub-samples were taken from storage containers with a 1-meter long open-handle spiral probe (Seedboro Equipment, Chicago, IL). Sub-samples were thoroughly mixed, and 2.2 Kg of the composite sample was collected, labeled, and placed in a double polyethylene bag for storage and subsequent testing. Soon after collection, samples were transported to a centralized location in each department where they were analyzed to determine the moisture content and approximate test weight using a DICKEY-john Mini GAC Plus (DICKEY-john, Auburn, IL). After initial testing, samples were frozen (-20°C) until transferred to the Food Analysis Laboratory at Zamorano University for mycotoxin analyses. In the laboratory, samples were kept at -20°C until analysis.

2.1.3.3. Sample preparation and mycotoxin analysis

All corn samples were ground in a Romer Series II laboratory mill (Romer Labs, Inc., Newark, DE). The mill was cleaned according to the manufacturer's instructions to avoid cross-contamination between samples. Before milling, sample moisture content was measured with a DICKEY-john GAC 500XT (DICKEY-john; Auburn, IL). If the moisture content was above the manufacturer's recommendation for milling, *i.e.*, > 15 percent, the corn kernels were dried in a forced-air oven at 40°C until the moisture content was between 13 and 15 percent.

Ground material was collected in a new polyethylene bag, thoroughly mixed and subsequently analyzed for aflatoxins and fumonisins using the monoclonal antibody-based affinity chromatography testing systems manufactured by VICAM (Milford, MA, USA). Total aflatoxins, *i.e.*, aflatoxins B_1, B_2, G_1, and G_2, were measured with the AflaTest® immunoaffinity columns; while total fumonisins, *i.e.*, fumonisins B_1, B_2, and B_3, were measured with FumoniTest® columns. The extraction and quantification of both toxins in a VICAM fluorometer (Series-4EX) was carried out according to VICAM's instruction manual. The limit of detection (LOD) for the aflatoxin and fumonisin quantification methods were 1 µg/Kg and 0.25 mg/Kg, respectively.

2.1.3.4. Data analysis

Data were analyzed with SAS software version 9.3 (SAS Institute, Cary, NC, USA), using a one-way analysis of variance (ANOVA) to compare the changes in mycotoxin contamination in response to sample location. ANOVAs were performed by using the GLIMMIX procedure of SAS. Tukey's multiple comparison test was used to determine significant differences in mean total aflatoxin and fumonisin among the departments and municipalities. All statistical analyses were performed with a significance level of $P \leq 0.05$. All values below the limit of detection were treated as "not detected" and assigned values of "zero" for calculating the incidences and means.

2.1.4. Key findings

2.1.4.1. Aflatoxin contamination in the corn supply chain in western Honduras

Aflatoxin contamination levels in high- and low-quality corn samples collected in the Western departments of Honduras are shown in Table 2.1.1. In this table the mean, median and range of aflatoxin contamination in corn by Department is detailed. When samples (high- and low-quality) were combined, in general, the frequency distribution of aflatoxin contamination in the corn supply chain from Western Honduras (Figure 2.1.2) indicates that the presence of this toxin in corn in this region is relatively low. Among the 740 samples analyzed, 146 (20 percent) had detectable levels of aflatoxin (> 1 µg/Kg) of which 51 (7 percent) and 105 (14 percent) were contaminated above the regulatory limit of 20 and 4 µg/Kg established by the U.S. Food and Drug Administration (FDA) and the European Commission, respectively.

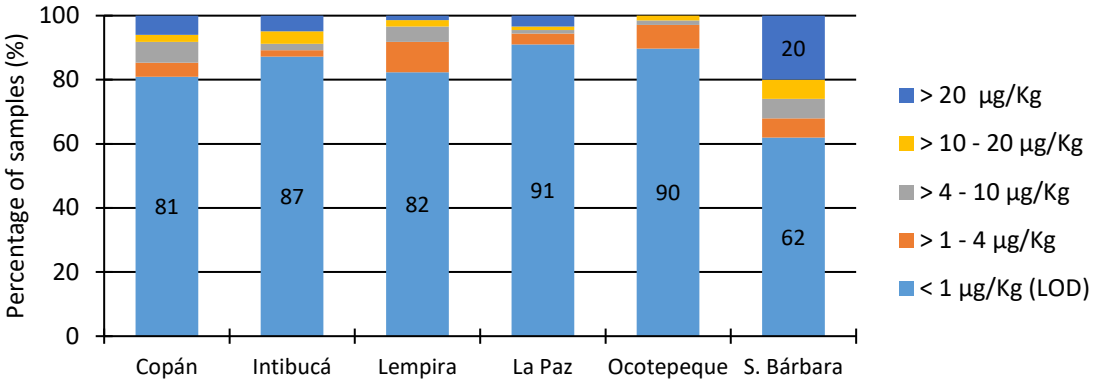


Figure 2.1.2 Combined frequency distribution of total aflatoxin, *i.e.*, aflatoxins B_1, B_2, G_1, G_2, in corn samples collected in the Western departments of Honduras. LOD = limit of detection (1 µg/Kg = 1 ppb). Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

Combined aflatoxin contamination was most common in corn samples from the department of Santa Bárbara (Fig. 2.1.2). Samples containing more than 1 µg/Kg (the detection limit for the affinity chromatography method) accounted for 38 percent of the 150 samples collected in this department. Among the positive samples, 53 percent (30 samples) exceeded the FDA maximum tolerated level. In contrast, aflatoxin contamination was much lower in the departments of La Paz and Ocotepeque. In La Paz, only 3/89 samples had aflatoxin in excess of the FDA regulatory limit, and none of the samples from Ocotepeque (68) had aflatoxin levels that exceeded the US regulatory threshold.

The mean and the incidence of aflatoxin contamination in corn samples collected from smallholder farmers and wholesale markets in the western departments of Honduras is summarized in Table 2.1.1.

In general, the average aflatoxin content of the food grade samples from smallholder farmers (6.5 ± 1.8 µg/Kg) did not differ significantly from the average found in samples purchased in the local markets (7.2 ± 3.3 µg/Kg). However, low quality corn samples intended for animal feed were contaminated at a significantly higher level (21.6 ± 7.2 µg/Kg) than were the samples destined for human consumption. If samples with no detectable aflatoxin were excluded from the analysis, then the average aflatoxin contamination level increased substantially from 6.5 to 41.0 µg/Kg in home-grown samples, and from 7.2 to 31.1 µg/Kg in market samples.

In Santa Bárbara, the department with the highest prevalence of aflatoxin contamination (Fig. 2.1.2), the average aflatoxin content in corn samples destined for human consumption collected from smallholders and local markets was 18.0 ± 6.9 and 26.6 ± 14.7 µg/Kg, respectively. The aflatoxin content in low quality corn collected in Santa Bárbara ranged from undetectable (<1 µg/Kg) to 490.0 µg/Kg, with

an average value of 51.9 ± 19.5 µg/Kg. Although most of the samples collected in the study region contained aflatoxin levels below regulatory limits, several samples contained levels known to be harmful to farm and laboratory animals and humans (1).

Table 2.1.1 Aflatoxin contamination levels in high- and low-quality corn samples collected in the western departments of Honduras.

Sample source (type) [1]	Department	Total samples (Positive samples) [2]	Total samples (µg/Kg) [3]			Positive samples (µg/Kg) [3]	
			Mean ± SEM	Median	Range	Mean ± SEM	Median
Producer (High quality corn)	Copán	111 (18)	11.0 ± 5.5 ab	0.0	ND [4] – 430.0	67.9 ± 31.5 a	11.5
	Intibucá	80 (10)	2.7 ± 1.2 ab	0.0	ND – 81.0	21.5 ± 7.2 a	18.5
	Lempira	103 (12)	0.7 ± 0.2 b	0.0	ND – 17.0	5.6 ± 1.4 a	4.1
	La Paz	64 (3)	0.9 ± 0.5 ab	0.0	ND – 22.0	19.7 ± 1.9 a	21.0
	Ocotepeque	54 (5)	0.6 ± 0.3 ab	0.0	ND – 16.0	5.9 ± 2.7 a	2.3
	Santa Bárbara	94 (32)	18.0 ± 6.9 a	0.0	ND – 490.0	52.8 ± 18.9 a	12.0
	Overall	**506 (80)**	**6.5 ± 1.8 y**	**0.0**	**ND – 490.0**	**41.0 ± 10.6 x**	**11.0**
Market (High quality corn)	Copán	43 (9)	2.3 ± 1.0 a	0.0	ND – 32.0	11.2 ± 3.6 a	6.8
	Intibucá	16 (2)	1.7 ± 1.3 a	0.0	ND – 20.0	13.5 ± 6.6 a	13.5
	Lempira	17 (4)	0.4 ± 0.2 a	0.0	ND – 2.1	1.8 ± 0.1 a	1.8
	La Paz	14 (3)	3.6 ± 2.9 a	0.0	ND – 40.0	16.6 ± 11.9 a	8.6
	Ocotepeque	8 (0)	ND	ND	ND	ND	ND
	Santa Bárbara	27 (11)	26.6 ± 14.7 a	0.0	ND – 390.0	65.2 ± 33.6 a	30.0
	Overall	**125 (29)**	**7.2 ± 3.3 y**	**0.0**	**ND – 390.0**	**31.1 ± 13.5 x**	**9.5**
Producer (Low quality corn)	Copán	30 (8)	8.8 ± 5.2 a	0.0	ND – 140.0	33.0 ± 17.6 b	6.6
	Intibucá	6 (1)	81.7 ± 81.7 a	0.0	ND – 490.0	490.0 ± 0.0 a	490.0
	Lempira	27 (10)	3.2 ± 1.3 a	0.0	ND – 22.0	8.6 ± 2.6 b	5.0
	La Paz	11 (2)	0.3 ± 0.2 a	0.0	ND – 1.5	1.5 ± 0.1 b	1.5
	Ocotepeque	6 (2)	0.5 ± 0.3 a	0.0	ND – 1.6	1.4 ± 0.2 b	1.4
	Santa Bárbara	29 (14)	51.9 ± 19.5 a	0.0	ND – 360.0	107.5 ± 35.2 b	43.0
	Overall	**109 (37)**	**21.6 ± 7.2 x**	**0.0**	**ND – 490.0**	**63.5 ± 19.5 x**	**13.0**

[1] Producer, samples collected from smallholders in rural areas; Market, samples collected from retail stores in urban areas. High quality = Human consumption; Low quality = Animal feed.

[2] Total samples, all samples analyzed; Positive samples, samples containing > 1 µg/Kg total aflatoxin (i.e., B1, B2, G1, G2).

[3] Mean ± Standard Error of the Mean (SEM). Within a single source/type of sample, means followed by different letters (a, b) are significantly different ($P \leq 0.05$). Overall mean values across different sample types/sources followed by different letters (x, y), differ significantly ($P \leq 0.05$).

[4] ND = Not Detected (below the limit of detection of the method, 1 µg/Kg).

2.1.4.2. Fumonisin contamination in the corn supply chain in Western Honduras

Fumonisin contamination levels in high- and low-quality corn samples collected in the Western departments of Honduras are shown in Table 2.1.2. In this table the mean, median and range of fumonisin contamination in corn by Department is detailed. When samples (high- and low-quality) were combined, unlike aflatoxins, fumonisins were substantially more prevalent and widespread in corn samples collected in the study region (Figure 2.1.3). Among the samples collected, over 97 percent (719 samples) had detectable levels of fumonisin (>0.25 mg/Kg).

Among the positive samples, 37 percent (268 samples) had fumonisin levels above the FDA advisory level of 3 mg/Kg, while 76 percent (544 samples) were contaminated above the regulatory limit of 1 mg/Kg set by the European Commission (EC) for corn destined for direct human consumption.

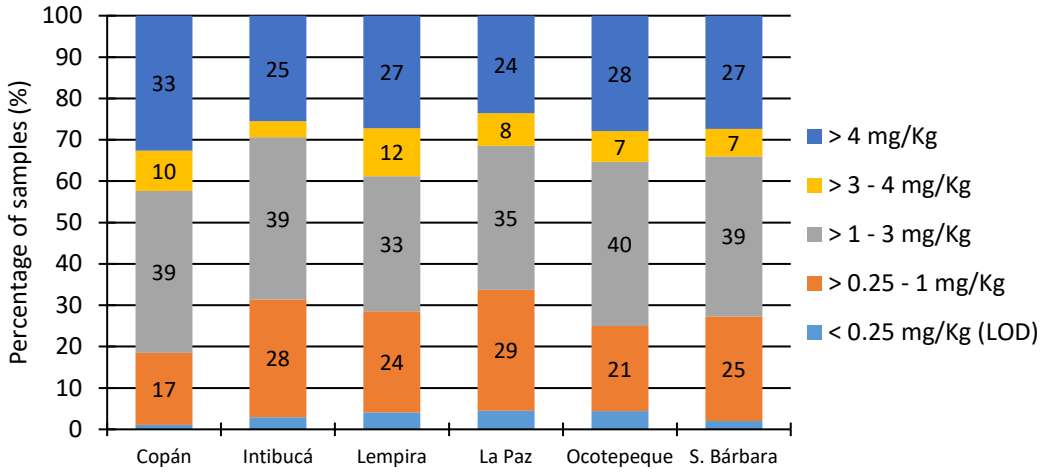


Figure 2.1.3 Combined frequency distribution of total fumonisin, *i.e.*, fumonisins B_1, B_2, and B_3, in corn samples collected in the Western departments of Honduras. Legend: LOD, limit of detection of the fumonisin quantification method; 1 mg/Kg = 1 ppm. Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

Comparison of the frequency distribution among all departments, showed that combined fumonisin contamination was most common in corn samples from Copán (Fig. 2.1.3.), where 43 percent of the samples (184) exceeded the FDA advisory level of 3 mg/Kg. In contrast, in Intibucá 29 percent of the samples (102) surpassed the same limit. When comparing fumonisin contamination levels against the EC regulations, 82 percent (150/184) of the Copán samples exceeded the EC maximum permitted level of 1 mg/Kg, the highest percentage among all the departments in the study.

The mean and the incidence of fumonisin contamination in corn samples collected from smallholder farmers and wholesale markets in the western departments of Honduras is summarized in Table 2.1.2. Regardless of the source, collected directly from farmers' own-grown stored grain or acquired in the market, the average fumonisin content in corn destined for human consumption was 3.0 mg/Kg. Thus, these data suggest that people who produce and consume their own corn are as exposed to high levels of fumonisin as those who obtain their corn in the marketplace from commercial vendors. Numerous samples collected throughout the study region contained fumonisin at levels known to cause diseases in farm animals and humans, including cancer and neural tube defects (1).

The corn samples intended for human consumption most highly contaminated with fumonisins were obtained from local markets in La Paz, with contamination levels ranging from 0.8 to 16.0 mg/Kg. Corn from samples destined for animal feed had significantly higher fumonisin contamination levels (7.6 ± 0.6 mg/Kg) than those levels in corn intended for human consumption (2.7 ± 0.1 mg/Kg). Low quality corn samples collected in the Copán and Lempira had the highest fumonisin contamination levels, with an average concentration of 9.9 ± 1.0 and 9.7 ± 1.4 mg/Kg, respectively.

The high incidence of fumonisin contamination in corn suggests that *Fusarium verticillioides* and *F. proliferatum* are likely to be a common, widely disseminated plant pathogens in Western Honduras; further research and mitigation are warranted. A warm and humid climate is quite conducive to the growth of and fumonisin production by these fungi (14). In Guatemala, fumonisin-producing strains of *F. verticillioides* were commonly encountered in the lowlands of the country where warm, humid climate prevails. In contrast, cool temperate environments, mainly encountered in highlands of Guatemala, were much less conducive to *F. verticillioides* infection and fumonisin production on corn (14). Therefore, we hypothesize that the climatic conditions prevailing in the study region are partly conducive to the proliferation of fumonisin-producing *Fusarium* species in the field, leading to the infection and contamination of the corn crop with fumonisin. Fumonisins are more commonly a pre-harvest problem than a post-harvest one since fumonisin production and *Fusarium* growth usually occur under wetter conditions than those required by *Aspergillus* species for the production of aflatoxins (9).

Table 2.1.2 Fumonisin contamination levels in high- and low-quality corn samples collected in the western departments of Honduras.

Sample source (type) [1]	Department	Total samples (Positive samples) [2]	Total samples (mg/Kg) [3]			Positive samples (mg/Kg) [3]	
			Mean ± SEM	Median	Range	Mean ± SEM	Median
Producer (High quality corn)	Copán	111 (109)	3.5 ± 0.4 a	2.0	ND [4] – 41.0	3.5 ± 0.5 a	2.0
	Intibucá	80 (77)	2.6 ± 0.3 a	1.6	ND – 12.0	2.7 ± 0.3 a	1.7
	Lempira	103 (100)	2.3 ± 0.2 a	1.7	ND – 9.8	2.4 ± 0.2 a	1.8
	La Paz	64 (61)	2.1 ± 0.3 a	1.4	ND – 11.0	2.2 ± 0.3 a	1.5
	Ocotepeque	54 (53)	3.1 ± 0.4 a	2.2	ND – 14.0	3.1 ± 0.4 a	2.3
	Santa Bárbara	94 (92)	2.7 ± 0.2 a	2.0	ND – 10.0	2.8 ± 0.2 a	2.2
	Overall	**506 (492)**	**2.7 ± 0.1 y**	**1.8**	**ND – 41.0**	**2.8 ± 0.1 y**	**1.8**
Market (High quality corn)	Copán	43 (43)	2.5 ± 0.3 b	2.0	0.3 – 8.8	2.5 ± 0.3 b	2.0
	Intibucá	16 (16)	3.5 ± 0.7 ab	3.1	0.3 – 8.7	3.5 ± 0.7 ab	3.1
	Lempira	17 (15)	3.0 ± 0.5 ab	2.6	ND – 8.1	3.4 ± 0.5 ab	2.7
	La Paz	14 (14)	5.4 ± 1.0 a	5.3	0.8 – 16.0	5.4 ± 1.0 a	5.3
	Ocotepeque	8 (7)	3.0 ± 0.9 ab	2.6	ND – 8.2	3.5 ± 0.9 ab	2.8
	Santa Bárbara	27 (27)	2.9 ± 0.5 b	2.3	0.3 – 13.0	2.9 ± 0.5 b	2.3
	Overall	**125 (122)**	**3.2 ± 0.2 y**	**2.4**	**ND – 16.0**	**3.2 ± 0.2 y**	**2.5**
Producer (Low quality corn)	Copán	30 (30)	9.9 ± 1.0 a	11.0	1.2 – 25.0	9.9 ± 1.0 ab	11.0
	Intibucá	6 (6)	3.5 ± 1.1 b	3.1	0.6 – 7.0	3.5 ± 1.1 ab	3.1
	Lempira	27 (26)	9.7 ± 1.4 a	12.0	ND – 31.0	10.1 ± 1.4 a	12.0
	La Paz	11 (10)	3.5 ± 1.3 b	1.1	ND – 12.0	3.8 ± 1.4 b	2.0
	Ocotepeque	6 (5)	5.3 ± 2.3 ab	3.2	ND – 14.0	6.4 ± 2.5 ab	4.8
	Santa Bárbara	29 (28)	5.9 ± 1.1 ab	2.1	ND – 20.0	6.2 ± 1.1 ab	2.4
	Overall	**109 (105)**	**7.6 ± 0.6 x**	**6.0**	**ND – 31.0**	**7.8 ± 0.6 x**	**7.0**

[1] Producer, samples collected from smallholders in rural areas; Market, samples collected from retail stores in urban areas. High quality = Human consumption; Low quality = Animal feed.

[2] Total samples, all samples analyzed; Positive samples, samples containing > 0.25 mg/Kg total fumonisin (i.e., B1, B2, and B3).

[3] Mean ± Standard Error of the Mean (SEM). Within a single source/type of sample, means followed by different letters (a, b) are significantly different ($P \leq 0.05$). Overall mean values across different sample types/sources followed by different letters (x, y), differ significantly ($P \leq 0.05$).

[4] ND = Not Detected (below the limit of detection of the method, 0.25 mg/Kg).

2.1.5. References

1. da Rocha, M. E. B., Freire, F. d. C. O., Maia, F. E. F., Guedes, M. I. F., and Rondina, D. 2014. Mycotoxins and their effects on human and animal health. *Food Control*, 36(1),159-165.
2. EuropeanUnion. Date, 2006, Commission regulation (EC) No. 1881/2006 of 19 December setting maximumlevels for certain contaminants in food stuffs. Official Journal of the European Union. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do? uri=OJ:L:2006:364:0005:0024:EN:PDF. Accessed, 2020.
3. Gelderblom, W., Marasas, W., Lebepe-Mazur, S., Swanevelder, S., Vessey, C., and De la M Hall, P. 2002. Interaction of fumonisin B1 and aflatoxin B1 in a short-term carcinogenesis model in rat liver. *Toxicology*, 171(2-3),161-173.
4. IFPRI. 2016. Feed the Future Honduras 2015 - Zone of Influence Interim Indicator Assessment. *In*, Washington, DC.
5. Khlangwiset, P., Shephard, G. S., and Wu, F. 2011. Aflatoxins and growth impairment: a review. *Critical reviews in toxicology*, 41(9),740-755.
6. Kimanya, M. E., De Meulenaer, B., Roberfroid, D., Lachat, C., and Kolsteren, P. 2010. Fumonisin exposure through maize in complementary foods is inversely associated with linear growth of infants in Tanzania. *Molecular nutrition & food research*, 54(11),1659-1667.
7. Logrieco, A., Mule, G., Moretti, A., and Bottalico, A. 2002. Toxigenic *Fusarium* species and mycotoxins associated with maize ear rot in Europe. p. 597-609. *In*, Mycotoxins in plant disease Springer.
8. McKean, C., Tang, L., Tang, M., Billam, M., Wang, Z., Theodorakis, C., Kendall, R., and Wang, J.-S. 2006. Comparative acute and combinative toxicity of aflatoxin B1 and fumonisin B1 in animals and human cells. *Food and Chemical Toxicology*, 44(6),868-876.
9. Pitt, J. I., Wild, C. P., Baan, R. A., Gelderblom, W. C., Miller, J., Riley, R., and Wu, F. 2012. Improving public health through mycotoxin control. International Agency for Research on Cancer, Lyon, France.
10. Riley, R. T., Torres, O., Matute, J., Gregory, S. G., Ashley-Koch, A. E., Showker, J. L., Mitchell, T., Voss, K. A., Maddox, J. R., and Gelineau-van Waes, J. B. 2015. Evidence for fumonisin inhibition of ceramide synthase in humans consuming maize-based foods and living in high exposure communities in Guatemala. *Molecular nutrition & food research*, 59(11),2209-2224.
11. Shirima, C. P., Kimanya, M. E., Routledge, M. N., Srey, C., Kinabo, J. L., Humpf, H.-U., Wild, C. P., Tu, Y.-K., and Gong, Y. Y. 2014. A prospective study of growth and biomarkers of exposure to aflatoxin and fumonisin during early childhood in Tanzania. *Environmental health perspectives*, 123(2),173-178.
12. Sweeney, M. J., and Dobson, A. D. 1998. Mycotoxin production by *Aspergillus*, *Fusarium* and *Penicillium* species. *International journal of food microbiology*, 43(3),141-158.

13. Torres, O., Matute, J., Gelineau-van Waes, J., Maddox, J., Gregory, S., Ashley-Koch, A., Showker, J., Voss, K., and Riley, R. 2014. Human health implications from co-exposure to aflatoxins and fumonisins in maize-based foods in Latin America: Guatemala as a case study. *World Mycotoxin Journal*, 8(2),143-159.
14. Torres, O. A., Palencia, E., de Pratdesaba, L. L., Grajeda, R., Fuentes, M., Speer, M. C., Merrill Jr, A. H., O'Donnell, K., Bacon, C. W., and Glenn, A. E. 2007. Estimated fumonisin exposure in Guatemala is greatest in consumers of lowland maize. *The Journal of nutrition*, 137(12),2723-2729.
15. Turner, P. C., Moore, S. E., Hall, A. J., Prentice, A. M., and Wild, C. P. 2003. Modification of immune function through exposure to dietary aflatoxin in Gambian children. *Environmental health perspectives*, 111(2),217-220.
16. Voth-Gaeddert, L. E., Stoker, M., Torres, O., and Oerther, D. B. 2018. Association of aflatoxin exposure and height-for-age among young children in Guatemala. *International journal of environmental health research*, 28(3),280-292.
17. Wang, H., Wei, H., Ma, J., and Luo, X. 2000. The fumonisin B1 content in corn from North China, a high-risk area of esophageal cancer. *Journal of environmental pathology, toxicology and oncology: official organ of the International Society for Environmental Toxicology and Cancer*, 19(1-2),139-141.
18. Williams, J. H., Phillips, T. D., Jolly, P. E., Stiles, J. K., Jolly, C. M., and Aggarwal, D. 2004. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. *The American journal of clinical nutrition*, 80(5),1106-1122.

2.2 WHAT OTHER TYPES OF MYCOTOXINS ARE PRESENT IN THE CORN VALUE CHAIN IN WESTERN HONDURAS?

2.2.1 Background

Mycotoxins are defined as low-molecular-weight natural products produced as secondary metabolites by fungi, that are harmful to humans and/or animals. These compounds are toxic to vertebrates and other animal groups in low concentrations, causing acute as well as chronic diseases (2). Different classes of mycotoxins often co-occur in a single agricultural commodity as some fungal species are capable of producing more than one secondary metabolite. Also, susceptible commodities can be colonized by multiple fungi if the environmental conditions, *e.g.*, temperature, relative humidity, and water activity, favor their growth either in the field or during storage. Therefore, a complex mixture of fungal metabolites may contaminate staple crops, such as corn.

2.2.2 Evaluation Objective(s)

To determine the identities and levels of fungal metabolites contaminating the corn supply chain in the Western departments of Honduras.

2.2.3 Methodology

2.2.3.1 Samples

A subset of 50 corn samples was selected from the 872 samples collected in the western departments of Honduras. Samples were selected in such a way to represent different departments, sources and postharvest handling practices. Each sample was ground in a Romer Series II laboratory mill (Romer Labs, Inc., Newark, DE). Ground material was thoroughly mixed, and a sub-sample of 40 g packaged in polypropylene conical tubes. Packed samples were sent to the Department of Agrobiotechnology at the University of Natural Resources and Life Sciences, Vienna (BOKU) in Tulln, Austria for screening of more than 250 fungal metabolites, including major regulated mycotoxins.

2.2.3.2 Analysis of fungal secondary metabolites

Fungal secondary metabolites in corn samples were analyzed using a multi-analyte LC-MS/MS method based on a “dilute and shoot” approach as described by Malachová et al. (6). Detection and quantification were performed with a QTrap 5500MS/MS system (Applied Biosystems, Foster City, CA) equipped with a TurboV electrospray ionization (ESI) source and a 1290 series UHPLC system (Agilent Technologies, Waldbronn, Germany).

2.2.4 Key Findings

A total of 74 fungal secondary metabolites from several fungal genera, including *Fusarium*, *Aspergillus*, *Penicillium*, *Diplodia* and *Alternaria* were detected in the corn samples. At least 4 of these metabolites are addressed by regulatory agencies worldwide. Table 2.2.1 shows the results of major regulated mycotoxin contamination classified by source and department.

Table 2.2.1 Contamination levels of major mycotoxins (other than aflatoxin and fumonisin) found in corn samples destined for human consumption in the western departments of Honduras.

Sample source (type)[1]	Department	Total samples	Nivalenol (µg/Kg) [2]		Zearalenone (µg/Kg) [2]		Citrinin (µg/Kg) [2]		Diplodiatoxin (µg/Kg) [2]	
			Mean ± SEM	Median	Mean ± SEM	Median	Mean ± SEM	Median	Mean ± SEM	Median
Producer (High quality)	Copán	4	96.9 ± 96.9	0.0	173.2 ± 172.6	0.8	1428.6 ± 750.5	1053.0	397.0 ± 385.9	16.9
	Intibucá	6	139.9 ± 83.6	35.4	139.5 ± 66.7	81.5	2114.8 ± 1973.5	48.2	474.4 ± 455.0	29.2
	Lempira	6	51.9 ± 33.2	21.1	94.7 ± 45.5	57.3	391.3 ± 277.9	31.9	202.5 ± 74.4	150.3
	La Paz	5	44.9 ± 20.9	23.5	7.4 ± 7.3	0.0	25.7 ± 23.2	4.5	252.2 ± 185.0	60.2
	Ocotepeque	4	136.1 ± 88.7	74.0	362.0 ± 359.0	4.4	4.7 ± 4.7	0.0	257.1 ± 172.0	137.0
	Santa Bárbara	7	25.0 ± 25.0	0.0	54.9 ± 52.5	0.0	5703.4 ± 2646.5	2522.7	429.8 ± 225.0	124.3
	Overall	**32**	**77.6 ± 23.6**	**0.0**	**124.0 ± 50.8**	**1.1**	**1900.7 ± 756.8**	**42.2**	**342.1 ± 108.5**	**58.4**
Market (High quality)	Copán	2	22.2 ± 22.2	22.2	4.3 ± 4.3	4.3	269.3 ± 266.0	269.3	54.2 ± 28.9	54.2
	Intibucá	5	104.2 ± 82.2	19.5	34.4 ± 27.2	2.5	108.7 ± 88.2	21.6	119.5 ± 46.7	79.4
	Lempira	2	25.6 ± 25.6	25.6	4.7 ± 4.7	4.7	6841.8 ± 1924.4	6841.8	82.8 ± 70.2	82.8
	La Paz	2	34.2 ± 34.2	34.2	6.3 ± 6.3	6.3	20669.8 ± 20468.0	20669.8	111.6 ± 89.8	111.6
	Ocotepeque	2	177.5 ± 113.4	177.5	77.5 ± 67.9	77.5	5.2 ± 5.2	5.2	31.8 ± 31.8	31.8
	Santa Bárbara	5	16.2 ± 16.2	0.0	25.4 ± 18.0	7.8	10281.4 ± 5237.6	5690.7	715.7 ± 296.0	814.5
	Overall	**18**	**62.3 ± 27.1**	**9.7**	**27.0 ± 11.6**	**8.4**	**5973.5 ± 2698.8**	**130.6**	**263.2 ± 103.2**	**81.3**

[1] Producer, samples collected from smallholders in rural areas; Market, samples collected from retail stores in urban areas. High quality = Human consumption.
[2] Values are corrected for recoveries. Mean ± Standard Error of the Mean (SEM).

2.2.5 Relevance

Among the major mycotoxins found by the laboratory in Austria were aflatoxins and fumonisins. Aflatoxin contamination was, on average, below regulatory limits (FDA: 20 µg/Kg) and was not even detected in most of the samples analyzed, whereas fumonisin was present in almost every sample and in many cases at levels that exceeded advisory/regulatory limits (FDA: 3 mg/Kg). In fact, the aflatoxin and fumonisin concentration levels found by the laboratory in Austria were very similar to the ones previously described in this report, which validates the results obtained by the laboratory at Zamorano University.

In addition to aflatoxins and fumonisins, other toxins produced by *Fusarium* fungi, including nivalenol and zearalenone, were found in the corn samples (Table 2.2.1). Given the high frequency of fumonisin contamination, which suggests the widespread presence of *Fusarium* species, it is not surprising to find other *Fusarium* toxins co-occurring in corn crops. Nivalenol and zearalenone can both by produced by the several species of *Fusarium*, but none of these species produce fumonisins. For instance, corn samples collected from smallholders had, on average, a nivalenol concentration of 77.6 ± 23.6 µg/Kg, whereas corn purchased in wholesale markets had a concentration of 62.3 ± 27.1 µg/Kg. Among the different departments, Intibucá and Ocotepeque had the highest levels of nivalenol with average contamination levels ranging from 104 to 177.5 µg/Kg. Nivalenol is one of several closely related trichothecene toxins that can be produced by multiple *Fusarium* species, including *F. graminearum*, *F. culmorum*, *F. cerealis* and *F. poae*. These microorganisms are both soil saprophytes and important pathogens of corn in the field. Although there are no data available on the effects of nivalenol on humans, research studies performed with laboratory animals and human cells have reported critical immunotoxicity and hepatotoxicity effects (8, 10). Currently, there are no regulatory limits for nivalenol, although the closely related deoxynivalenol is regulated in many countries including the United States and the European Union.

Zearalenone, another *Fusarium* toxin, was found at levels of 124 ± 50.8 µg/Kg in corn samples obtained from smallholder farmers. Commercial corn samples had substantially lower zearalenone levels, with an average value of 27.0 ± 11.6 µg/Kg. Intibucá and Ocotepeque were among the departments with the highest zearalenone contamination levels. Zearalenone is not regulated by the FDA; however, the EC has established maximum tolerated levels in corn intended for direct human consumption at 100 µg/Kg. Some samples, especially from the departments of Intibucá and Ocotepeque, exceeded the EC regulatory level for this toxin. Zearalenone is produced by many *Fusarium* species, and has been best studied in *F. graminearum*. Although zearalenone is primarily a field contaminant, toxin production also may occur under poor storage conditions. This toxin has oestrogenic activity and is implicated in mycotoxicoses in farm animals, primarily swine, resulting in alterations in the reproductive system and decreased fertility *(14).* In humans, this toxin may also alter the hormonal balance (5).

Although some samples exceeded regulatory limits for multiple *Fusarium* toxins, including fumonisin, nivalenol and zearalenone, numerous samples had extremely high concentrations of citrinin and diplodia toxin. Citrinin is a toxic metabolite produced by several filamentous fungal species in the genera *Penicillium*, *Aspergillus* and *Monascus*. This toxin usually is synthesized after harvest under storage conditions and occurs most commonly in stored grain (1). Temperatures of 15–30°C and humidity levels > 16 percent favor the growth of citrinin-producing fungi on grain. Currently, there are no regulatory levels for citrinin in cereal grain; however, the EC has established a maximum level of citrinin in food supplements based on rice fermented with the red yeast *Monascus purpureus*. This regulatory level was recently lowered from 2000 to 100 µg/Kg (3). Citrinin was found at levels of 1900.7 ± 756.8 µg/Kg in corn samples from smallholders, and commercial corn samples were contaminated at substantially higher levels, with an average value of 5970 ± 2700 µg/Kg. The highest levels of citrinin were found in Santa Bárbara, with contamination levels averaging 5700 ± 2650 µg/Kg in home-grown samples and 10300 ± 5240 µg/Kg in commercial samples. When compared to the EC regulatory levels for food supplements (100 µg/Kg), most of the samples analyzed contained extremely high levels of citrinin that exceeded by many folds the maximum permitted level. The kidney is the main target organ for citrinin (4), But there also is clear evidence from laboratory animal studies for reproductive toxicity and teratogenic and embryotoxic effects of citrinin (1, 4).

Regarding diplodiatoxin, corn samples from smallholders had, on average, a concentration of 342 ± 109 µg/Kg, while commercial samples had a lower average content of 263 ± 103 µg/Kg. Samples from Santa Bárbara were the most highly contaminated, with an average of 429 µg/Kg in home-grown samples and 716 µg/Kg in commercial samples. Diplodiatoxin is produced primarily by the fungi *Stenocarpella maydis* (=*Diplodia maydis)*, which is a common contaminant of corn crops worldwide. In rats, this toxin causes changes in liver enzymes (12, 13). In sheep and cattle, frequent ingestion of diplodiatoxin is linked to a neuromuscular paretic syndrome (diplodiosis), which is characterized by a high-stepping posture, incoordination, paresis, paralysis, and death (11). Outbreaks of diplodiosis have occurred in South Africa and Argentina where cattle are commonly allowed to graze harvested corn fields (7, 9, 11). Currently, no regulatory limits have been set for diplodiatoxin anywhere in the world.

2.2.6 References

1. Čulig, B., Bevardi, M., Bošnir, J., Serdar, S., Lasić, D., Racz, A., Galić, A., and Kuharić, Ž. 2017. Presence of citrinin in grains and its possible health effects. *African Journal of Traditional, Complementary and Alternative Medicines*, 14(3),22-30.
2. da Rocha, M. E. B., Freire, F. d. C. O., Maia, F. E. F., Guedes, M. I. F., and Rondina, D. 2014. Mycotoxins and their effects on human and animal health. *Food Control*, 36(1),159-165.

3. EUROPEAN COMMISSION. Date, 2019, SUMMARY REPORT OF THE STANDING COMMITTEE ON PLANTS, ANIMALS, FOOD AND FEED HELD IN BRUSSELS ON 29 MARCH 2019. Available at: https://ec.europa.eu/food/sites/food/files/safety/docs/reg-com_toxic_20190329_sum.pdf. Accessed, 2020.
4. European Food Safety Authority. Date, 2012, Scientific Opinion on the risks for public and animal health related to the presence of citrinin in food and feed. Available at: https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2012.2605. Accessed, 2020.
5. Kowalska, K., Habrowska-Górczyńska, D. E., and Piastowska-Ciesielska, A. W. 2016. Zearalenone as an endocrine disruptor in humans. *Environmental toxicology and pharmacology*, 48,141-149.
6. Malachová, A., Sulyok, M., Beltrán, E., Berthiller, F., and Krska, R. 2014. Optimization and validation of a quantitative liquid chromatography–tandem mass spectrometric method covering 295 bacterial and fungal metabolites including all regulated mycotoxins in four model food matrices. *Journal of Chromatography A*, 1362,145-156.
7. Masango, M., Flett, B., Ellis, C., and Botha, C. 2015. Stenocarpella maydis and its toxic metabolites: a South African perspective on diplodiosis. *World Mycotoxin Journal*, 8(3),341-350.
8. Minervini, F., Fornelli, F., and Flynn, K. 2004. Toxicity and apoptosis induced by the mycotoxins nivalenol, deoxynivalenol and fumonisin B1 in a human erythroleukemia cell line. *Toxicology in vitro*, 18(1),21-28.
9. Odriozola, E., Odeon, A., Canton, G., Clemente, G., and Escande, A. 2005. Diplodia maydis: a cause of death of cattle in Argentina. *New Zealand Veterinary Journal*, 53(2),160-161.
10. PETTERSSON, H., and HEDMAN, R. 1997. Toxicity and metabolism of nivalenol in farm animals. *Cereal Research Communications*,423-427.
11. Rabie, C., Kellerman, T., Kriek, N., Van der Westhuizen, G., and De Wet, P. 1985. Toxicity of Diplodia maydis in farm and laboratory animals. *Food and Chemical Toxicology*, 23(3),349-353.
12. Rabie, C., Van Rensburg, S., Kriek, N., and Lübben, A. 1977. Toxicity of Diplodia maydis to laboratory animals. *Appl. Environ. Microbiol.*, 34(2),111-114.
13. Rahman, M., Rao, S. K., and Achar, P. 2002. Effect of diplodiatoxin (Stenocarpella maydis) on some enzymatic profiles in male and female rats. *Ecotoxicology and environmental safety*, 52(3),267-272.
14. Rogowska, A., Pomastowski, P., Sagandykova, G., and Buszewski, B. 2019. Zearalenone and its metabolites: Effect on human health, metabolism and neutralisation methods. *Toxicon*.

2.3 ARE THERE CERTAIN AREAS OF THE ZOI THAT HAVE HIGHER LEVELS OF MYCOTOXIN CONTAMINATION THAN OTHER AREAS? ELEVATION, PRECIPITATION, AND OTHER VARIABLES MAY AFFECT THE PRESENCE OF MYCOTOXINS.

2.3.1 Background

Honduras is a tropical country with varying topographical regions. In the West, the mountains have the highest peaks, with elevations between 2500-2850 meters above sea level (masl). In the East, the mountains reach 2300-2400 masl. Contrastingly, numerous flat floored valleys of 300-1200 masl are scattered throughout the interior highlands of the country. Subsistence agriculture usually occurs on the slopes of the valleys, with the limitations of low productivity (*1*, *6*).

The regional variation in elevation influences Honduras' temperature. Therefore, there is a temperature fluctuation with altitude rather than a change with seasons. Regions located below 1000 masl are known as *tierras calientes* (hot land), between 1000-2000 masl are *tierras templadas* (temperate land), and above 2000 masl *tierras frías* (cold land) (6). Regions below 460 masl have average annual temperatures of 26-28°C. The north coast is occasionally affected from October to April by cool northern winds. Mountain basins and valleys (600-1200 masl) have mean annual temperatures of 19-23°C. As elevation increases, ca. 2100 masl, the average annual temperatures approach as low as 14°C (1). The rainy season starts in May and continues until mid-November. In the northern and eastern coastal and alluvial plains and on adjacent mountains, the average precipitation ranges from 70-110 inches (1800-2800 mm). Pacific plains and mountain slopes get 60-80 in. (1500-2000 mm) of rain annually. Interior sheltered mountain basins and valleys receive 40-70 in. (1000-1800 mm) annually (1). The country is highly vulnerable to its variable climate. Between 1998 and 2017, Honduras experienced more damage caused by extreme weather events than any other country on earth, ranking first in the German watch Climate Change Vulnerability Index. Extreme rainfall, atypical droughts, variation in the dates of rainfall, loss of fertility and erosion of arable land are all critical problems for agriculture in the country (3, 4).

These climatic variations can result in plant stress, facilitating attacks by mycotoxin-producing fungi (7). When it comes to the geological distribution, aflatoxins and fumonisins are documented to be the major mycotoxins found in the Africa and Asian subcontinents and in Australia; aflatoxins, fumonisins, ochratoxin, zearalenone, and deoxynivalenol in North America; aflatoxins, fumonisins, ochratoxin, deoxynivalenol and T-2 toxin in South America; zearalenone and deoxynivalenol in Eastern Europe; and ochratoxin, zearalenone, and deoxynivalenol in Western Europe (*2*). However, due to global climate change, increase in international trade and other global humanitarian food aid activities, mycotoxins historically associated with a particular region also can be found in other parts of the world.

2.3.2 Evaluation Objective

To understand if regions within the ZOI are prone to mycotoxin contamination due to geo-location. Results from this research can help identify the distribution of mycotoxin contamination in Western Honduras.

2.3.3 Methodology

Samples collected from ZOI (See Question 2.1 for sample detail) were classified by their respective municipality elevation. Average aflatoxin or fumonisin contamination is additionally reported as a heat map to better conceptualize regional mycotoxin contamination (fragmented per municipality). Trends were evaluated.

2.3.4 Key Findings

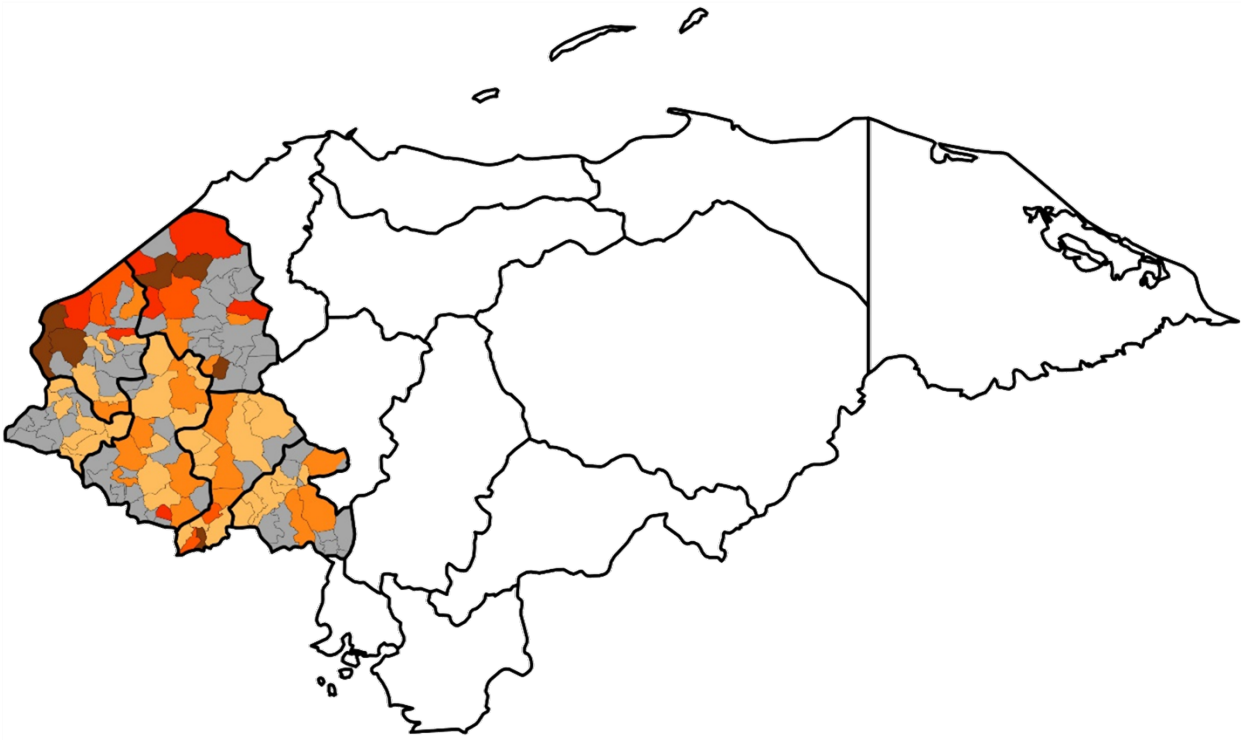


Figure 2.3.1 Heatmap of average 2017-2018 aflatoxin levels in corn samples collected in the Western departments of Honduras. The intensity of color for each municipality corresponds to the related total aflatoxin level. Range of contamination <1 µg/Kg (■), ≥1 – 4 µg/Kg (■), >4 – 10 µg/Kg (■), >10 – 20 µg/Kg (■), >20 µg/Kg (■). Non-analyzed municipalities are shown in gray (■).

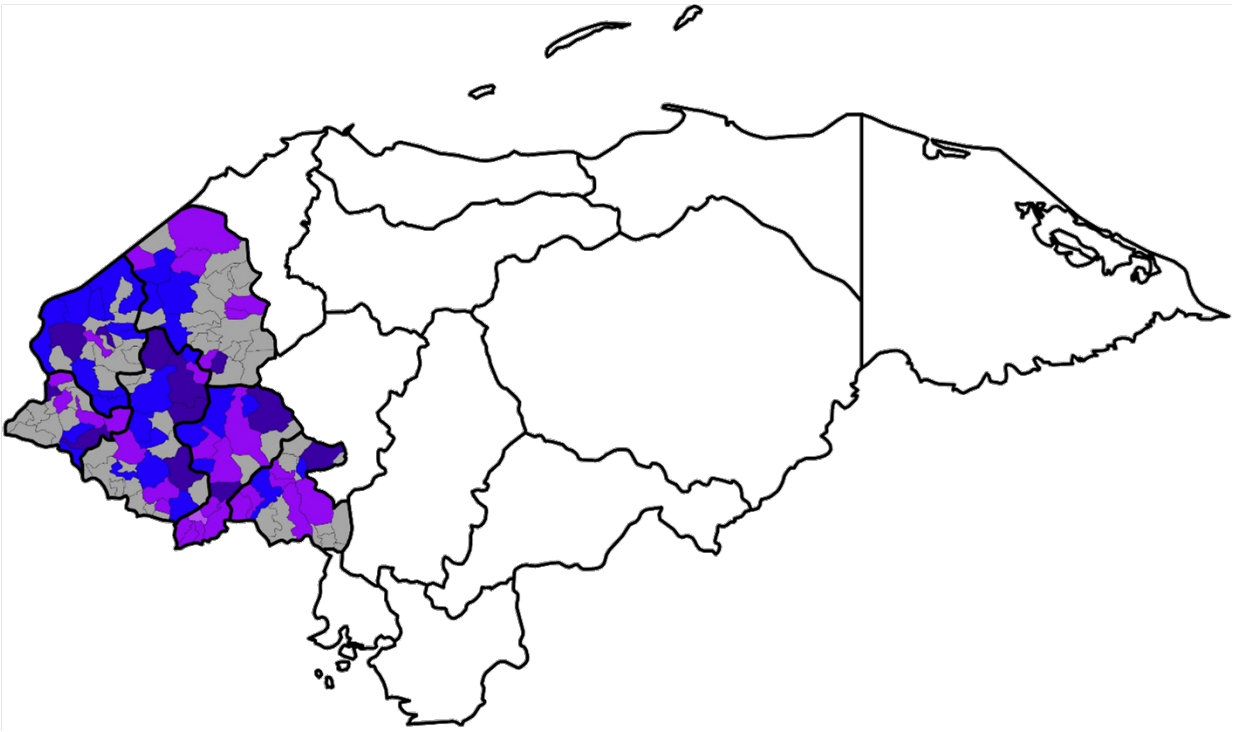


Figure 2.3.2 Heatmap of average 2017-18 fumonisin levels in corn samples collected in the Western departments of Honduras. The intensity of color for each municipality corresponds to the related total fumonisin level. Range of contamination <0.25 mg/Kg (), 0.25 – 1 mg/Kg (), >1 – 3 mg/Kg (), >3 – 4 mg/Kg (), >4 mg/Kg (). Non-analyzed municipalities are shown in gray ().

Table 2.3.1 Aflatoxin and fumonisin contamination levels in corn samples collected in different municipalities in western Honduras.

Department	Municipality by Elevation (masl[0])	Total samples [1] (Positives AF/FU)	Aflatoxin (µg/Kg) [2]			Fumonisin (mg/Kg) [2]		
			Mean ± SEM	Median	Range	Mean ± SEM	Median	Range
Santa Bárbara	Gualala (113)	7 (1 / 7)	1.6 ± 1.6 ab	0.0	ND - 11.0	2.6 ± 0.5 a	2.2	1.0 - 4.8
	Macuelizo (206)	20 (11 / 20)	80.1 ± 30.4 ab	1.4	ND - 390.0	4.5 ± 1.1 a	2.7	0.5 - 20.0
	Quimistán (211)	24 (9 / 24)	31.9 ± 21.0 ab	0.0	ND - 490.0	3.3 ± 0.4 a	2.7	0.5 - 6.9
	San Marcos (267)	12 (7 / 11)	42.6 ± 27.5 ab	11.7	ND - 340.0	1.5 ± 0.3 a	1.1	ND - 3.6
	Ilama (298)	10 (6 / 10)	17.0 ± 6.9 ab	8.0	ND - 66.0	3.3 ± 0.9 a	2.0	0.5 - 8.9
	Santa Rita (364)	8 (2 / 8)	6.5 ± 5.2 ab	0.0	ND - 42.0	3.3 ± 1.5 a	1.9	0.3 - 13.0
	Nueva Frontera (630)	8 (2 / 8)	17.8 ± 17.5 ab	0.0	ND - 140.0	1.5 ± 0.3 a	1.2	0.8 - 2.7
	El Nispero (650)	8 (1 / 6)	1.4 ± 1.4 ab	0.0	ND - 11.0	2.6 ± 0.9 a	2.4	ND - 6.8
	Protección (905)	19 (9 / 19)	15.7 ± 10.4 ab	0.0	ND - 200.0	4.2 ± 0.8 a	2.9	0.4 - 13.0
	Atima (978)	17 (2 / 17)	0.8 ± 0.6 ab	0.0	ND [3] - 9.8	4.2 ± 1.1 a	2.2	0.3 - 15.0
	San Luis (1036)	17 (7 / 17)	15.1 ± 7.8 ab	0.0	ND - 130.0	3.4 ± 1.1 a	1.2	0.5 - 14.0
	Overall	**150 (57 / 147)**	**25.9 ± 6.3 x**	**0.0**	**ND - 490.0**	**3.4 ± 0.3 xy**	**2.2**	**ND - 20.0**
Copán	Florida (475)	23 (5 / 23)	6.6 ± 2.9 ab	0.0	ND - 53.0	4.6 ± 1.1 a	1.8	0.6 - 18.0
	Santa Rita (550)	23 (4 / 22)	20.3 ± 18.6 ab	0.0	ND - 430.0	3.3 ± 0.6 a	2.4	ND - 11.0
	Copán Ruinas (582)	25 (7 / 25)	22.0 ± 17.2 ab	0.0	ND - 420.0	5.7 ± 1.8 a	1.8	0.3 - 41.0
	San Antonio (587)	8 (2 / 8)	12.0 ± 11.0 ab	0.0	ND - 89.0	6.4 ± 1.9 a	4.6	1.3 - 16.0
	Nueva Arcadia (663)	27 (7 / 26)	2.4 ± 1.2 ab	0.0	ND - 32.0	3.7 ± 0.9 a	2.2	ND - 25.0
	San José (798)	5 (0 / 5)	ND	ND	ND	3.9 ± 0.9 a	3.7	1.2 - 5.9
	San Pedro (836)	7 (0 / 7)	ND	ND	ND	3.3 ± 2.0 a	1.6	0.3 - 15.0
	Trinidad de Copán (860)	7 (1 / 7)	10.9 ± 10.9 ab	0.0	ND - 76.0	6.7 ± 1.6 a	7.2	0.4 - 12.0
	Corquín (901)	13 (1 / 13)	0.7 ± 0.7 ab	0.0	ND - 9.7	3.1 ± 0.5 a	2.6	0.8 - 7.0
	La Unión (935)	15 (1 / 15)	0.2 ± 0.2 ab	0.0	ND - 2.9	5.6 ± 1.3 a	2.8	0.9 - 14.0
	Concepción (1013)	4 (2 / 4)	1.7 ± 1.3 ab	0.6	ND - 5.4	3.5 ± 0.8 a	3.1	1.9 - 5.8
	Dolores (1167)	6 (1 / 6)	1.0 ± 1.0 ab	0.0	ND - 5.7	4.5 ± 1.6 a	3.2	0.7 - 11.0
	Overall	**184 (35 / 182)**	**8.6 ± 3.4 y**	**0.0**	**ND - 430.0**	**4.4 ± 0.4 x**	**2.4**	**ND - 41.0**

[0] meters above sea level (masl)

[1] Total samples, all samples analyzed; Positive samples for aflatoxin (AF) and fumonisin (FU) are samples containing > 1 µg/Kg total aflatoxin (i.e., B1, B2, G1, G2) and > 0.25 mg/Kg total fumonisin (i.e., B1, B2, and B3), respectively.

[2] Mean ± Standard Error of the Mean (SEM). Within the same column, across different departments, mean values or overall mean values followed by different letters (mean, a-b; overall mean, x-y) are significantly different ($P \leq 0.05$).

[3] ND = Not Detected (below the limit of detection of the method for aflatoxin (1 µg/Kg) or fumonisin (0.25 mg/Kg).

Table 2.3.1 *Continued.*

Department	Municipality by Elevation (masl[0])	Total samples [1] (Positives AF/FU)	Aflatoxin (µg/Kg) [2]			Fumonisin (mg/Kg) [2]		
			Mean ± SEM	Median	Range	Mean ± SEM	Median	Range
Ocotepeque	San Jorge (897)	3 (0 / 3)	ND	ND	ND	4.1 ± 2.1 a	2.3	1.7 - 8.3
	San Fr. Valle (898)	8 (2 / 8)	0.5 ± 0.3 ab	0.0	ND - 2.2	4.5 ± 1.1 a	4.1	0.9 - 10.0
	Sensenti (918)	10 (1 / 9)	0.2 ± 0.2 ab	0.0	ND - 2.1	2.3 ± 0.6 a	1.8	ND - 5.7
	San Marcos (989)	16 (1 / 15)	0.1 ± 0.1 ab	0.0	ND - 2.3	3.1 ± 0.7 a	2.8	ND - 9.8
	Mercedes (1240)	6 (0 / 6)	ND	ND	ND	4.8 ± 2.1 a	2.6	0.9 - 14.0
	San Fernando (1249)	5 (0 / 5)	ND	ND	ND	2.3 ± 0.6 a	1.9	1.2 - 4.5
	Fraternidad (1516)	5 (0 / 5)	ND	ND	ND	2.1 ± 0.8 a	0.9	0.8 - 4.8
	Belén Gualcho (1785)	15 (3 / 14)	1.7 ± 1.2 ab	0.0	ND[3] - 16.0	2.5 ± 0.7 a	1.9	ND - 8.2
	Overall	**68 (7 / 65)**	**0.5 ± 0.3 y**	**0.0**	**ND - 16.0**	**3.1 ± 0.3 xy**	**2.3**	**ND - 14.0**
Lempira	Piraera (761)	6 (3 / 6)	2.5 ± 1.3 ab	1.1	ND - 8.1	6.0 ± 2.2 a	4.7	0.4 - 13.0
	Candelaria (799)	3 (1 / 3)	7.0 ± 7.0 ab	0.0	ND - 21.0	2.6 ± 0.3 a	2.8	2.0 - 3.0
	Gracias (800)	23 (1 / 23)	0.3 ± 0.3 ab	0.0	ND - 8.0	3.9 ± 0.7 a	3.1	0.4 - 15.0
	Belén (964)	5 (0 / 5)	ND	ND	ND	3.2 ± 2.2 a	0.9	0.3 - 12.0
	Lepaera (1037)	23 (2 / 23)	0.4 ± 0.3 ab	0.0	ND - 6.3	2.9 ± 0.6 a	2.3	0.5 - 15.0
	Tambla (1150)	3 (2 / 3)	2.4 ± 1.6 ab	1.7	ND - 5.5	8.8 ± 3.2 a	12.0	2.3 - 12.0
	Erandique (1254)	14 (5 / 13)	1.7 ± 0.9 ab	0.0	ND - 11.0	3.8 ± 1.7 a	0.9	ND - 22.0
	La Iguala (1418)	14 (3 / 11)	1.5 ± 1.2 ab	0.0	ND - 17.0	2.8 ± 0.8 a	1.6	ND - 9.8
	La Unión (1418)	10 (3 / 9)	0.6 ± 0.3 ab	0.0	ND - 2.1	6.1 ± 2.9 a	2.9	ND - 31.0
	S. M. Colohete (1418)	9 (1 / 9)	2.4 ± 2.4 ab	0.0	ND - 22.0	4.5 ± 1.4 a	3.7	0.5 - 13.0
	San Rafael (1418)	7 (1 / 7)	0.2 ± 0.2 ab	0.0	ND - 1.1	2.7 ± 0.4 a	2.6	1.4 - 4.8
	San M. Caiquin (1418)	5 (1 / 5)	1.1 ± 1.1 ab	0.0	ND - 5.4	5.8 ± 2.6 a	2.4	0.9 - 13.0
	Gualcince (1519)	7 (1 / 7)	0.3 ± 0.3 ab	0.0	ND - 2.4	3.0 ± 0.8 a	3.2	0.8 - 6.8
	San Sebastián (1695)	8 (1 / 8)	2.3 ± 2.3 ab	0.0	ND - 18.0	1.2 ± 0.4 a	0.7	0.4 - 4.0
	San Andrés (1706)	10 (1 / 9)	0.1 ± 0.1 ab	0.0	ND - 1.2	4.1 ± 1.5 a	2.1	ND - 14.0
	Overall	**147 (26 / 141)**	**1.1 ± 0.3 y**	**0.0**	**ND - 22.0**	**3.8 ± 0.4 xy**	**2.3**	**ND - 31.0**

[0] meters above sea level (masl)

[1] Total samples, all samples analyzed; Positive samples for aflatoxin (AF) and fumonisin (FU) are samples containing > 1 µg/Kg total aflatoxin (i.e., B1, B2, G1, G2) and > 0.25 mg/Kg total fumonisin (i.e., B1, B2, and B3), respectively.

[2] Mean ± Standard Error of the Mean (SEM). Within the same column, across different departments, mean values or overall mean values followed by different letters (mean, a-b; overall mean, x-y) are significantly different ($P \leq 0.05$).

[3] ND = Not Detected (below the limit of detection of the method for aflatoxin (1 µg/Kg) or fumonisin (0.25 mg/Kg).

Table 2.3.1 *Continued*.

Department	Municipality by Elevation (masl[0])	Total samples [1] (Positives AF / FU)	Aflatoxin (µg/Kg) [2]			Fumonisin (mg/Kg) [2]		
			Mean ± SEM	Median	Range	Mean ± SEM	Median	Range
Intibucá	San Antonio (148)	4 (0 / 4)	ND	ND	ND	1.2 ± 0.3 a	1.2	0.5 - 1.7
	Magdalena (295)	4 (3 / 4)	149.0 ± 114.9 a	53.0	ND - 490.0	2.2 ± 0.8 a	1.7	1.0 - 4.5
	Santa Lucia (420)	3 (1 / 3)	6.3 ± 6.3 ab	0.0	ND - 19.0	3.1 ± 1.9 a	1.4	1.0 - 7.0
	Concepcion (495)	9 (2 / 9)	5.0 ± 3.0 ab	0.0	ND - 22.0	1.8 ± 0.4 a	2.1	0.3 - 4.1
	Camasca (791)	2 (0 / 1)	ND [3]	ND	ND	0.3 ± 0.3 a	0.3	ND - 0.6
	Colomoncagua (882)	6 (0 / 5)	ND	ND	ND	1.3 ± 0.4 a	1.2	ND - 3.2
	Dolores (947)	3 (0 / 3)	ND	ND	ND	5.1 ± 1.8 a	5.7	1.7 - 8.0
	San Isidro (1117)	2 (0 / 2)	ND	ND	ND	5.3 ± 0.5 a	5.3	4.8 - 5.8
	San Miguelito (1156)	6 (0 / 6)	ND	ND	ND	2.8 ± 1.5 a	1.2	0.4 - 9.6
	San Juan (1157)	5 (0 / 4)	ND	ND	ND	2.7 ± 0.7 a	2.8	ND - 4.8
	San M. Sierra (1191)	5 (1 / 5)	2.2 ± 2.2 ab	0.0	ND - 11.0	3.9 ± 1.3 a	2.7	1.6 - 8.5
	San F. Opalaca (1500)	5 (1 / 5)	5.6 ± 5.6 ab	0.0	ND - 28.0	4.0 ± 2.0 a	2.1	0.6 - 12.0
	Intibucá (1700)	23 (2 / 23)	0.4 ± 0.3 ab	0.0	ND - 6.9	2.2 ± 0.5 a	1.3	0.5 - 9.5
	Jesus De Otoro (1700)	13 (2 / 13)	0.6 ± 0.5 ab	0.0	ND - 6.7	4.0 ± 0.6 a	4.0	1.1 - 8.7
	Yamaranguila (1728)	12 (1 / 12)	1.5 ± 1.5 ab	0.0	ND - 18.0	3.3 ± 1.3 a	1.0	0.3 - 12.0
	Overall	**102 (13 / 99)**	**7.1 ± 4.8 y**	**0.0**	**ND - 490.0**	**2.8 ± 0.3 y**	**1.7**	**ND - 12.0**
La Paz	Marcala (687)	12 (1 / 11)	0.1 ± 0.1 ab	0.0	ND - 1.5	3.6 ± 1.2 a	1.5	ND - 12.0
	La Paz (750)	28 (4 / 27)	2.4 ± 1.6 ab	0.0	ND - 40.0	3.7 ± 0.6 a	2.8	ND - 16.0
	San P. Tutule (1246)	2 (0 / 2)	ND	ND	ND	4.5 ± 2.7 a	4.5	1.8 - 7.1
	San Jose (1325)	7 (0 / 7)	ND	ND	ND	2.6 ± 0.8 a	2.5	0.5 - 5.4
	Opatoro (1490)	9 (1 / 8)	2.3 ± 2.3 ab	0.0	ND - 21.0	1.9 ± 0.7 a	1.1	ND - 7.0
	Chinacla (1500)	7 (0 / 7)	ND	ND	ND	1.8 ± 0.4 a	1.5	0.9 - 4.2
	Yarula (1740)	4 (0 / 4)	ND	ND	ND	1.7 ± 0.8 a	1.4	0.3 - 3.9
	Santa Elena (1800)	12 (0 / 12)	ND	ND	ND	2.3 ± 0.9 a	1.2	0.3 - 11.0
	Guajiquiro (1807)	8 (2 / 7)	2.9 ± 2.7 ab	0.0	ND - 22.0	1.3 ± 0.4 a	0.9	ND - 3.6
	Overall	**89 (8 / 85)**	**1.3 ± 0.6 y**	**0.0**	**ND - 40.0**	**2.8 ± 0.3 y**	**1.6**	**ND - 16.0**

[0] meters above sea level (masl)

[1] Total samples, all samples analyzed; Positive samples for aflatoxin (AF) and fumonisin (FU) are samples containing > 1 µg/Kg total aflatoxin (i.e., B1, B2, G1, G2) and > 0.25 mg/Kg total fumonisin (i.e., B1, B2, and B3), respectively.

[2] Mean ± Standard Error of the Mean (SEM). Within the same column, across different departments, mean values or overall mean values followed by different letters (mean, a-b; overall mean, x-y) are significantly different ($P \leq 0.05$).

[3] ND = Not Detected (below the limit of detection of the method for aflatoxin (1 µg/Kg) or fumonisin (0.25 mg/Kg).

Corn mycotoxin data collected for every municipality was arranged based on altitude and grouped by department. Aflatoxin contamination, while present (Table 2.3.1), was not widespread in 2017-18, as several municipalities had readings below the limit of detection (1 µg/Kg). Santa Bárbara and Copán had the highest levels of contamination, with the most severe cases occurring at lower altitudes (<600 masl). Fumonisin contamination is prevalent in the ZOI, with Lempira, Santa Bárbara and Copán having the highest levels of contamination. Trends for altitude effect on fumonisin contamination are not evident. For Ocotepeque and La Paz, it appears the mid-altitudes (800-900 masl) had the highest fumonisin levels. For Intibucá, higher altitudes had higher fumonisin contamination levels. No clear pattern was observed for the distribution of fumonisin contamination in Lempira, Santa Bárbara, and Copán, where varying fumonisin levels were detected at different altitudes.

While aflatoxin was found in few instances (Figure 2.3.1), it appears that fumonisin-producing fungi are endemic to the ZOI and could extend throughout the country. A comprehensive study by Julian *et al.* (5) encompassing the Eastern part of Honduras showed similar contamination trends. Samples from different origins. *i.e*., field or storage, often tested negative for aflatoxin while most were highly contaminated with fumonisins (68-6555 mg/Kg range). Fluctuating temperatures, moisture levels *in planta* and during storage, as well as current field management practices are not effectively controlling the formation of these mycotoxins, allowing primary and secondary fungal disease cycles to occur and allowing field fungi to thrive on the plants in later stages.

2.3.5 References

1. Clegern, W. M., J. R. Moncada R., and R. L. Woodward. 2019. República de HondurasEncyclopædia Britannica. Encyclopædia Britannica Inc.
2. Devegowda, G., M. V. L. Radu, A. Nazar, and H. V. L. M. Swamy. 1998. Mycotoxin picture worldwide: novel solutions for their counteractionProceedings of Alltech's 14th annual symposium, biotechnology in feed industry. Nottingham Univ. Press, Nottingham, U.K.
3. Eckstein, D., M.-L. Hutfils, and M. Winges. 2019. Global Climate Risk Index 2019. Bonn, Germany.
4. Global Security. 2019. Honduras - Climate. *Military*.
5. Julian, A. M., P. W. Wareing, S. I. Phillips, V. F. P. Medlock, M. V. MacDonald, and L. E. del Rio. 1995. Fungal contamination and selected mycotoxins in pre- and post-harvest maize in Honduras. *Mycopathologia* 129:5–16.
6. Merrill, T. 1995. Honduras: A Country Study. GPO for the Library of Congress, Washington.
7. Prandini, A., S. Sigolo, L. Filippi, P. Battilani, and G. Piva. 2009. Review of predictive models for Fusarium head blight and related mycotoxin contamination in wheat. *Food Chem. Toxicol.* Elsevier Ltd 47:927–931.

2.4 WHAT VARIABLES, SUCH AS LOCATION, DRYING METHOD, LENGTH OF STORAGE, STORAGE METHODS, ETC. AFFECT THE PRESENCE OF MYCOTOXINS?

2.4.1 Background

Despite substantial advances in scientific methodologies, many years of advanced research and a large number of publications about mycotoxins, the accurate prediction of conditions for mycotoxin synthesis in field and in storage remains a challenge. Apart from moisture and temperature, other important factors that favor mold growth and mycotoxin synthesis in cereal crops include pH, substrate, pest damage, plant stress conditions, competition from other microbes, oxygen and CO_2 levels (mycotoxin producing fungi are highly aerobic in nature), and the presence of antimycotic agents (7, 8, 11, *18*, *20*). Moreover, since proper grain drying and storage are important farming processes essential for guaranteeing household food security, traditional drying and storage practices in developing countries such as Honduras may not assure either the security or the safety of the grain (10, 25).

Damage caused by pests accounts for up to 30 percent of corn post-harvest losses (21), particularly when no agrochemicals are used. This loss affects families' well-being both financially and in terms of food availability (17), negatively affecting their resilience. In addition to quantitative losses, pests commonly are associated with mycotoxin contamination, which compromises food and feed safety. Furthermore, subsistence farmers may have no choice but to consume some or all of the damaged product to avoid starvation (4). Depending on the mycotoxin consumed, there are a wide array of symptoms ranging from emesis to systemic cancer, and death that can result (5, 22, 23). To avoid post-harvest losses from pests and microorganisms during storage, smallholder farmers often barter or to sell their corn soon after harvest (4, 12) when prices are low, only to buy it back a few months later at a higher price. Even though traditional grain practices including storage methods are favored by farmers, since they require little or essentially no investment, they lead to substantial losses over time and contribute to food insecurity. Therefore, promoting improvements in small-scale agricultural practices is key to achieving food security in developing countries (*21*, *25*) including Honduras.

2.4.2 Evaluation Objective

Determine grain handling variables that could have an influence in the mycotoxin level of corn samples collected in the ZOI. The results from this assessment can help better define which of the current storage practices can lower toxin levels.

2.4.3 Methodology

Information about production and handling practices used by smallholder farmers in rural areas and by retail stores in urban locations was obtained using a questionnaire (see supporting documents in Appendix 1) designed to suit the purpose of the study. Information gathered included type of seeds planted, *e.g.*, native or improved, intercropping, time of harvest, drying and storage practices, pest control, and consumption patterns. The survey was conducted when samples were collected. Key

questions and responses are included in this section as they pertain to grain quality and handling practices, and how these practices may influence mycotoxin contamination of staples.

2.4.4 Key Findings

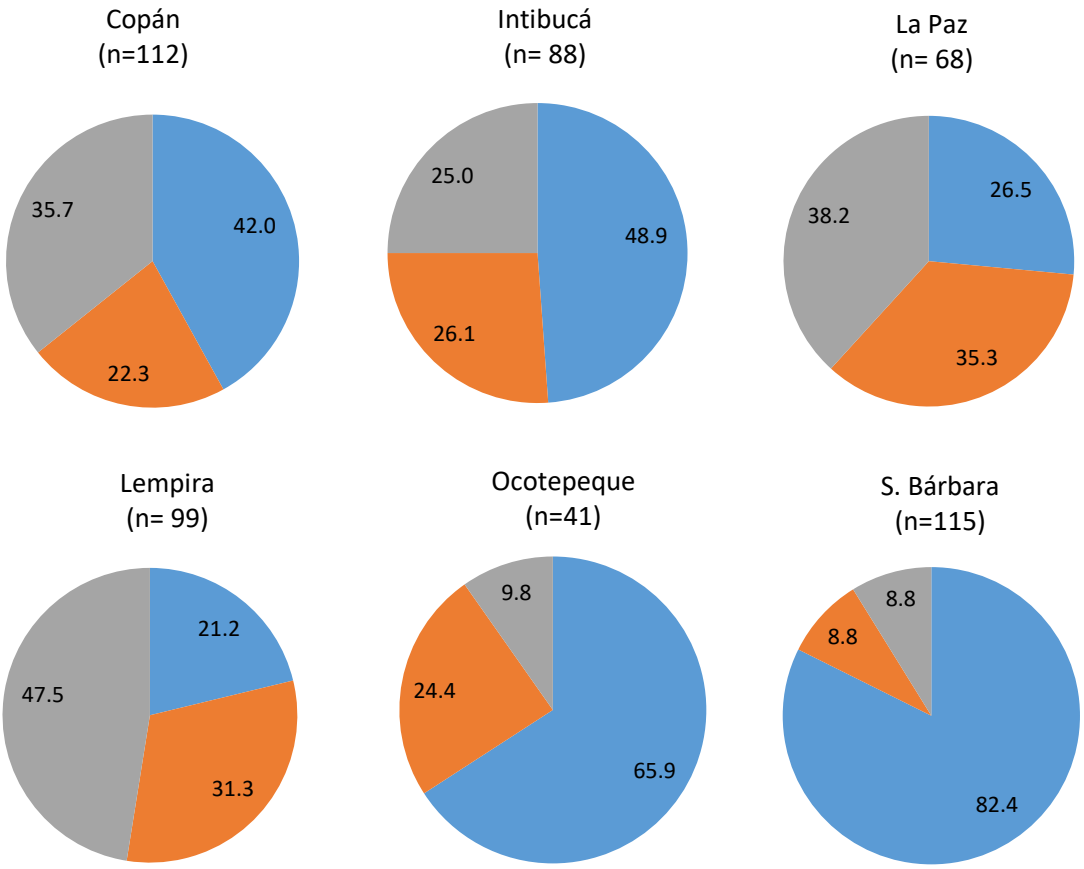


Figure 2.4.1 Corn storage moisture for corn growers in the Western departments of Honduras. Range of moisture levels <=14 percent (■), >14-16 percent (■), >16 percent (■). Number of responses per department denoted by *n*.

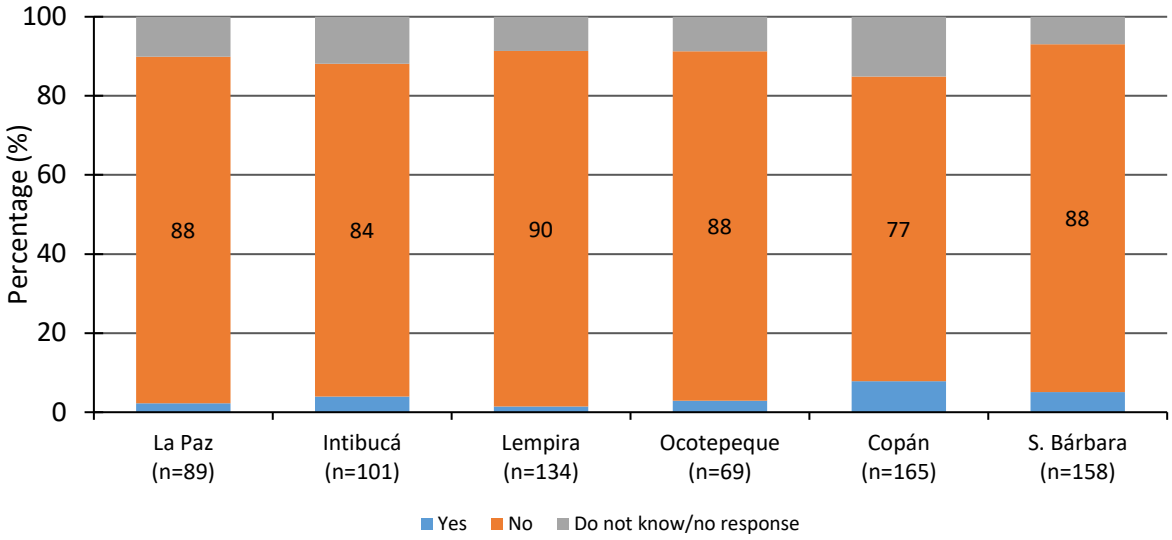


Figure 2.4.2 Occurrence of performing *"dobla"* (bending of plants in field) among corn growers from the western departments of Honduras. Number of responses per department denoted by *n*. Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

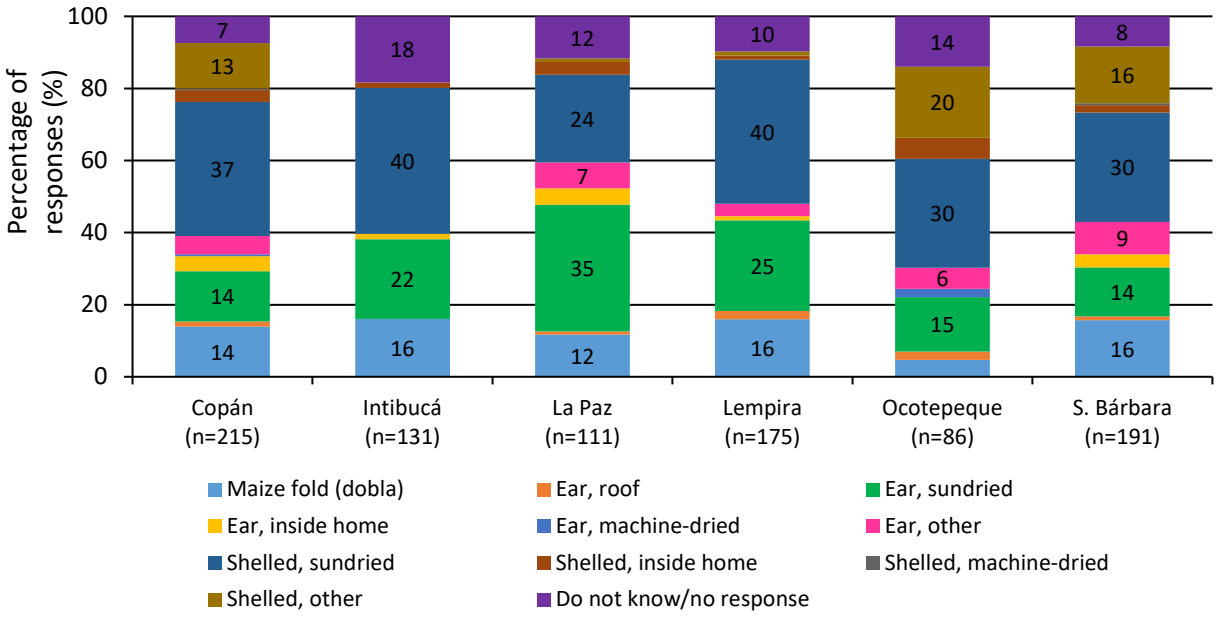


Figure 2.4.3 Drying practices for ears of corn or shelled corn used by growers in Western departments of Honduras. Each color used on the graph represents how the corn was dried (ear or shelled) and where* (i.e. roof of the house, machine-dried). Number of responses per department denoted by *n*. Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

*_Other_: Either solar dryers or "_manteado_" (process where corn is dried laid on fabric). _Dobla_: bending plant in field.

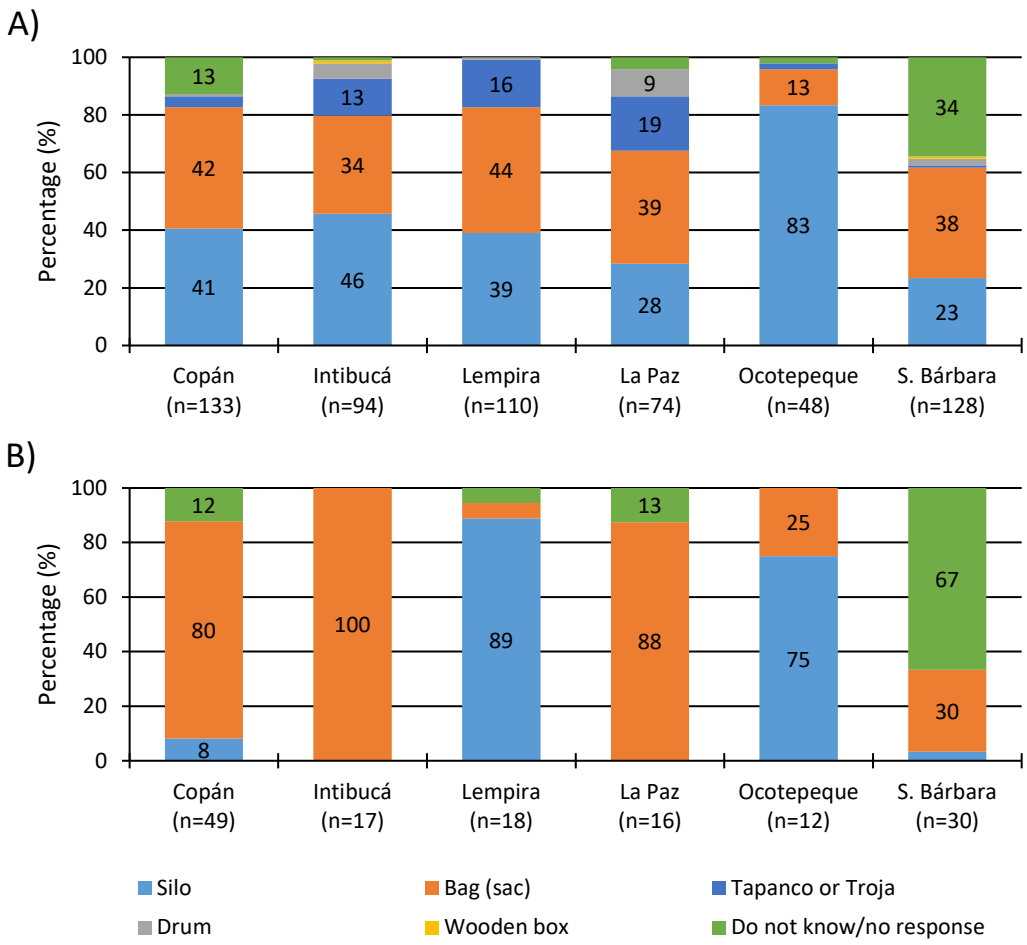


Figure 2.4.4 Corn storage type for growers (A) and corn marketers (B) in the Western departments of Honduras. Number of responses per department denoted by *n*. Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

The unpredictable weather in Honduras, which is conducive to fungal growth and mycotoxin production, is a factor out of the control of Honduran corn growers. Nonetheless, there are several practices that could be implemented in the ZOI to alleviate the current conditions to some extent.

For Honduran farmers that have assigned specific plots of land to continuous corn production, the monoculture cycle (21) should be broken and corn rotated with other cash crops. This rotation will decrease pathogen loads in the field due to a lack of a suitable host to infect. Similarly, during land preparation for the next season, avoiding tillage, a common practice in developing nations (2), can be risky since it leaves fungal resting structures that can lead to disease problems and colonization of other growing plants and neighboring hosts.

Early in the corn production chain, Honduran farmers tend to leave the corn for an unnecessary amount of time in the field after it is physiologically mature and ready for harvest (later discussed under Question 2.6. Figure 2.6.1). This practice is preferred by many growers in the ZOI due to the low moisture content when harvested (Figure 2.4.1). This prolonged interaction with the elements enables pests such as rats and birds to damage corn ears, creating entry points for fungi. Furthermore, Figure 2.4.2 depicts how several farmers (>70 percent) across the ZOI do not perform the bending of the corn plant (turning down the corn stalk after maturity, while in the field) during later growth stages. The bending of the corn stalk can facilitate early drying and protection from pests (i.e. birds) (*13*, *14*).

Once harvested, another issue that arises is the insufficient drying as one of the main causes of spoilage reported by inhabitants of Western Honduras (later discussed under Question 2.7. Figure 2.7.1). The typical drying methods practiced in Western Honduras are shown in Figure 2.4.3. Sun drying of ears and shelled corn is the preferred practice to decrease the moisture levels of corn. Environmental conditions in Honduras however do not allow for a fast-drying process at all times. Inadequately dried, the corn is then placed under storage. Storage conditions of above 70 percent relative humidity and corn moisture content of above 14 percent will decrease grain quality over time, even more so when there is no restricted access (e.g. exposed trojas or tapancos) to pests nor prompt treatment with pesticides and fungicides when necessary (*6*, *15*, *16*, *19*). Furthermore, non-hermetic bags (sacos), while being effective for transport from farms to markets and households, are not an effective barrier against insect pests and fungi (*3*, *9*, *24*); nevertheless, this is one of the most common storage vessels in Honduras (Figure 2.4.4). Positively, many corn growers and marketers use metallic silos, which do offer (semi) hermeticity (*21*) and thus an improved control of aerobic organisms including mycotoxigenic fungi.

It is also worth mentioning that pre-harvest good agricultural practices (GAPs) are very important in controlling mycotoxin contamination. In general, farmer practices that increase yield also reduce mycotoxin risk. Therefore, provided that storage technology users effectively manage their fields (proper tillage, adapted seed selection, fertilizer, pest management) as well as a prompt drying of their harvest prior to storage (*1*, *5*), emerging low cost storage alternatives offer promising results against mycotoxin-producing fungi as part of an integrated strategy.

2.4.5 References

1. Alberta Agriculture and Forestry. 2010. Cereal Grain Drying and Storage. *Adapt. from Canada Grain Counc. Complet. Guid. to Wheat Manag.*
2. Bockus, W. W., and J. P. Shroyer. 1998. The impact of reduced tillage on soilborne plant pathogens. *Annu. Rev. Phytopathol.* 36:485–500.
3. Bokusheva, R., R. Finger, M. Fischler, R. Berlin, Y. Marín, F. Pérez, and F. Paiz. 2012. Factors determining the adoption and impact of a postharvest storage

technology. *Food Secur.* 4:279–293.
4. Boxall, R. A. 2002. Damage and loss caused by the Larger Grain Borer Prostephanus truncatus. *Integr. Pest Manag. Rev.* 7:105–121.
5. Bravo, J. 2009. Metal Silos and Food Security, 1st ed. Ibarra, Ecuador.
6. Bravo Martinez, J. 2009. Metal silos and food security. Lessons Learned from a Successful Central American Post-harvest program. Quito, Ecuador.
7. Channaiah, L. H., and D. E. Maier. 2014. Best Stored Maize Management Practices for the Prevention of Mycotoxin Contamination, p. 78–89. *In* A.F. Logrieco, and J.F. Leslie (eds.), Mycotoxin Reduction in Grain Chains. John Wiley & Sons, Ltd, Hoboken, NJ, USA.
8. Channaiah, L. H. 2019. An Overview of Mycotoxicosis and Human's Health Concerns: A Mini-Review. *Nov Tech Nutr. Food Sci.* 4:303–305.
9. Dowell, F. E., and C. N. Dowell. 2017. Reducing grain storage losses in developing countries. *Qual. Assur. Saf. Crop. Foods* 9:93–100.
10. FAO. 2009. Post-harvest losses aggravate hunger. *News Artic.*
11. FAO. 1979. Recommended practices for the prevention of mycotoxins in food, feed and their products. *FAO Food Nutr Pap.* 10:1–71.
12. FAO, and IPGRI. 2002. The role of women in the conservation of the genetic resources of maize, 1st ed. Rome.
13. Fuentes, R. M. 2002. El cultivo del maiz en Guatemala. Una guía para su manejo agronómico.
14. Instituto de Ciencia y Tecnologia Agricolas (ICTA). 2014. Recomendaciones técnicas para el cultivo de maiz para zonas de produccion comprendidas entre 0 a 1400 msnm. Guatemala.
15. Leslie, J. F., and A. F. Logrieco. 2014. Mycotoxin Reduction in Grain Chains, 1st ed. John Wiley & Sons, Inc., Manhattan, Kansas.
16. López, M. F. 2002. Una guía para su manejo agronómico del maíz. Guatemala.
17. Manuel, I., R. Abel, G. Muñoz, B. Ramírez, V. J. Hilario, S. M. Bellon, R. F. Mexicana, I. M. Rosas, A. G. Muñoz, B. R. Valverde, and J. H. H. Salgado. 2007. Physical and physiological seed quality of maize landraces stored in metalic silo and with traditional methods in Oaxaca, Mexico. *Rev. Fitotec. Mex.* 30:69–78.
18. Milani, J. M. 2013. Ecological conditions affecting mycotoxin production in cereals: A review. *Vet. Med. (Praha).* 58:405–411.
19. Nash, M. J. 1985. Crop conservation and storageSecond. Pergamon Press, England.
20. Shapira, R., and M. Paster. 2004. Control of mycotoxins in storage and techniques for their decontamination, p. 190–223. *In* N. Magan, and M. Olsen (eds.), Mycotoxins in food: detection and control. Woodhead Publishing Ltd, Cambridge.
21. Tefera, T., F. Kanampiu, H. De Groote, J. Hellin, S. Mugo, S. Kimenju, Y. Beyene, P. M. Boddupalli, B. Shiferaw, and M. Banziger. 2011. The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Prot.* Elsevier Ltd 30:240–245.
22. Torres, O., J. Matute, J. Gelineau-van Waes, J. R. Maddox, S. G. Gregory, A. E.

Ashley-Koch, J. L. Showker, K. A. Voss, and R. T. Riley. 2015. Human health implications from co-exposure to aflatoxins and fumonisins in maize-based foods in Latin America: Guatemala as a case study. *World Mycotoxin J.* 8:143–159.

23. Torres, O. a, E. Palencia, L. Lopez de Pratdesaba, R. Grajeda, M. Fuentes, M. C. Speer, A. H. Merrill, K. O'Donnell, C. W. Bacon, A. E. Glenn, and R. T. Riley. 2007. Estimated fumonisin exposure in Guatemala is greatest in consumers of lowland maize. *J. Nutr.* 137:2723–2729.
24. Walker, S., R. Jaime, V. Kagot, and C. Probst. 2018. Comparative effects of hermetic and traditional storage devices on maize grain: Mycotoxin development, insect infestation and grain quality. *J. Stored Prod. Res.* Elsevier Ltd 77:34–44.
25. Yusuf, B. L., and Y. He. 2011. Design , development and techniques for controlling grains post-harvest losses with metal silo for small and medium scale farmers. *African J. Biotechnol.* 10:14552–14561.

2.5 DOES EXPOSURE TO MYCOTOXINS VARY BY GENDER? IN OTHER WORDS, IS THERE A DIFFERENTIAL MYCOTOXIN EXPOSURE BETWEEN MEN AND WOMEN?

2.5.1 Background

Corn (*Zea mays*) is considered one of the most important cereals grown in the Republic of Honduras. In 2019 alone 600,000 metric tons of corn were imported into the country, in addition to the 520,000 metric tons produced, totaling a consumption of 1,120,000 metric tons (*7*). Nonetheless, this popular grain staple is prone to fungal infestation in different stages of the corn production chain. Furthermore, some of the fungi interacting with corn are capable of producing harmful mycotoxins. Once inside the host, these toxic compounds can exert a variety of acute and chronic effects on humans and animals depending on species and susceptibility of an animal within a species (*26*). Exposure to mycotoxins is a serious risk to human health, especially in developing countries where rising poverty and malnutrition increase the detrimental effects of these food-borne fungal toxins by restricting biochemical detoxification mechanisms (*18*).

Historically, two mycotoxins have been most closely associated with corn: aflatoxins and fumonisins. Aflatoxins are produced by different *Aspergillus* species, the most predominant being *A. flavus* and *A. parasiticus* (*19*). Acute severe aflatoxin intoxication may result in liver damage, illness or death, while chronic sublethal doses have been linked with childhood stunting, as well as nutritional disparities and immunologic consequences (*8*, *20*, *23*). Fumonisins are produced by different *Fusarium* species, predominantly by *F. verticillioides* in corn (*3*, *13*, *15*). Consumption of fumonisin-contaminated corn has been associated with an elevated risk for human esophageal cancer, perturbed sphingolipid metabolism, and embryonic neural tube defects (*11*, *12*, *16*). Consumption of mycotoxin-contaminated staples becomes of concern for developing nations such as Honduras, where poverty coupled with unregulated local markets, tropical weather fluctuations and traditional crop storage vessels are habitually conducive to fungal growth, ultimately resulting in the consumption of contaminated food.

Risk assessments of mycotoxins in food based on toxicological studies done by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) help establish maximum levels in food or provide other risk management advice to control or prevent mycotoxin contamination. As a result, an established group Provisional Maximum Tolerable Daily Intake (PMTDI) of 2 μg/kg bw/day for fumonisin B1, B2 and B3, alone or in combination, has been defined by JECFA (*22*). While there is no official PMTDI for aflatoxin, previous studies have recognized and recommended that daily exposure levels should not exceed 0.001 μg aflatoxin/kg bw/day (*10*, *21*, *25*). To this, other variables ought to be taken into consideration, gender being of importance. Recent data on amounts of corn consumption by Honduran men and women are not readily available. However, based on estimates for Central America and Mexico by Bressani (*2*) adult men consume approximately 600 g of corn per day, and according to Ohri-Vachaspati and Swindale (*14*) Honduran women consume an average of 567 g of corn per day. For

nursing mothers in areas of high mycotoxin incidence this can result in children being exposed to aflatoxin M1, the hydroxylated metabolite of aflatoxin B1 through breast milk (*17*). Likewise, a carry-over of fumonisin to breast milk is also possible (*9*).

2.5.2 Evaluation Objective

To estimate the fumonisin and aflatoxin dietary exposure for adult Honduran men and women. Findings of this research can help infer possible acute and chronic health risks for female and male inhabitants of the ZOI in Western Honduras.

2.5.3 Methodology

Mycotoxin (fumonisin or aflatoxin) contamination levels for each municipality (Question 2.3) were used for a toxicity exposure assessment. This data set included 918 fumonisin tests and 897 aflatoxin tests. The number of test results included in this assessment is higher than the number of samples collected because some samples had more than one sub-sample evaluated for confirmatory purposes. To accomplish the exposure assessment, in addition to mycotoxin levels, information on daily average (male and female) corn consumption and average adult weight (male and female) were also used. Average Central American weights of 76.2 kg for men and 58.1 kg for women (*24*) were used for calculations, along with a daily average corn consumption level of 600 g for men and 567 g for women. Exposures to maximum, average and median levels of either total fumonisins or total aflatoxins were estimated based on equation 2.5.1. Summarized results can be seen on Figures 2.5.1 and 2.5.2.

$$\text{Mycotoxin exposure} = \frac{\text{Mycotoxin content}\left[\frac{\mu g}{kg}\right] * \text{Corn consumption}\left[\frac{kg}{day}\right]}{\text{Average body weight [kg]}} \qquad \boldsymbol{Eq.\,2.5.1}$$

2.5.4 Key Findings

It can be seen on Figure 2.5.1 that most municipalities showed low levels of aflatoxin exposure as the median in most cases was zero; it should be noted that this does not confirm that aflatoxin is absent from maize in these areas, since larger sample sizes across multiple seasons and points of the value chain would no doubt uncover some extent of aflatoxin presence. For both genders, the few instances where the median was quantifable took place in Santa Bárbara (Ilama, Protección and San Marcos municipalities), and Intibucá (Magdalena and Santa Lucía municipalities) with the lowest case being 0.009 µg of aflatoxin per kg bw/day, nine times the recommended limit. In general, on average for the detectable cases of aflatoxin, exposure estimates were 55 and 68 times the suggested aflatoxin PMTDI for men and women, respectively.

Fumonisin exposure (Figure 2.5.2) in Western Honduras takes place in all of the region of study. Analyzed corn samples revealed widespread contamination with fumonisin-producing fungi as all municipalities showed results above the limit of detection (0.25 ppm = 250 µg/kg). In all cases, estimated exposure levels surpassed the PMTDI of 2.00 µg/kg bw/day for both gender exposure estimates. Overall, on average, fumonisin exposure was 14 and 16 times the PMTDI for men and women, respectively. Some

instances (i.e. maximum contamination levels) resulted in exposure levels surpassing 150 times the PMTDI. Exposure assessment showed slightly higher levels in women as they tend to be shorter than men, but with similar daily corn consumption quantities, therefore rendering a higher exposure.

Even consumption of aflatoxin-contaminated corn with low contamination levels can result in exposures surpassing the suggested limit. This is attributed to the Honduran diet, which similar to Mexican and other Central American diets is heavily reliant on corn (*14*), with several grain-based foods consumed (e.g. tortillas, atole, tamales) on a daily basis. This less diverse diet can consequently facilitate lower levels to attain toxicity thresholds. Fumonisin was more prominent than aflatoxin as it was detected in all municipalities of the ZOI, with every exposure estimation level exceeding the PMTDI established by JECFA. Strategies to prevent lactating mothers from fumonisin exposure are desirable to minimize fumonisin exposure in Honduran infants.

Several studies involving *in vitro* digestion assays (*1*, *4*, *5*, *6*) suggest disparities between the amount of mycotoxin ingested and the amount of mycotoxin readily absorbed by the body. This takes into consideration possible mycotoxins bound to other compounds in the food matrix, rendering them undetectable prior to digestion under traditional platforms. However, when contaminated food is digested, these compounds could be partially released, increasing the total daily toxin quota. For the Honduran population, this could mean that already severe levels of mycotoxin contamination (i.e. fumonisin) could be many folds larger when calculated through a bio-accessibility assay.

Given the likelihood of similar grain handling practices taking place in other regions of the country not included in this study, findings indicate the possibility of mycotoxin contamination in multiple departments other than those in the ZOI. Therefore, mitigation strategies should be disseminated across Honduras to decrease any possible population exposure to different mycotoxins (see Questions 2,6).

Addressing mycotoxin exposure for the Honduran population is one of the initial steps towards decreasing the existing constraint on attempts to improve human health. This exploratory study revealed mycotoxin contamination in corn harvested or sold and consumed in various municipalities throughout Western Honduras. Inhabitants of the region will likely continue to consume contaminated staples to maintain their household food security. Thus, one of the first steps in recognizing mycotoxins as a food safety challenge should include community education on early prevention strategies. Here, women play an important role (See Question 7) as they are often leading seed selection (pre- and post-harvest), as well as food preparation and other nutrition-related procedures, all with potential to ultimately decrease household toxin exposure.

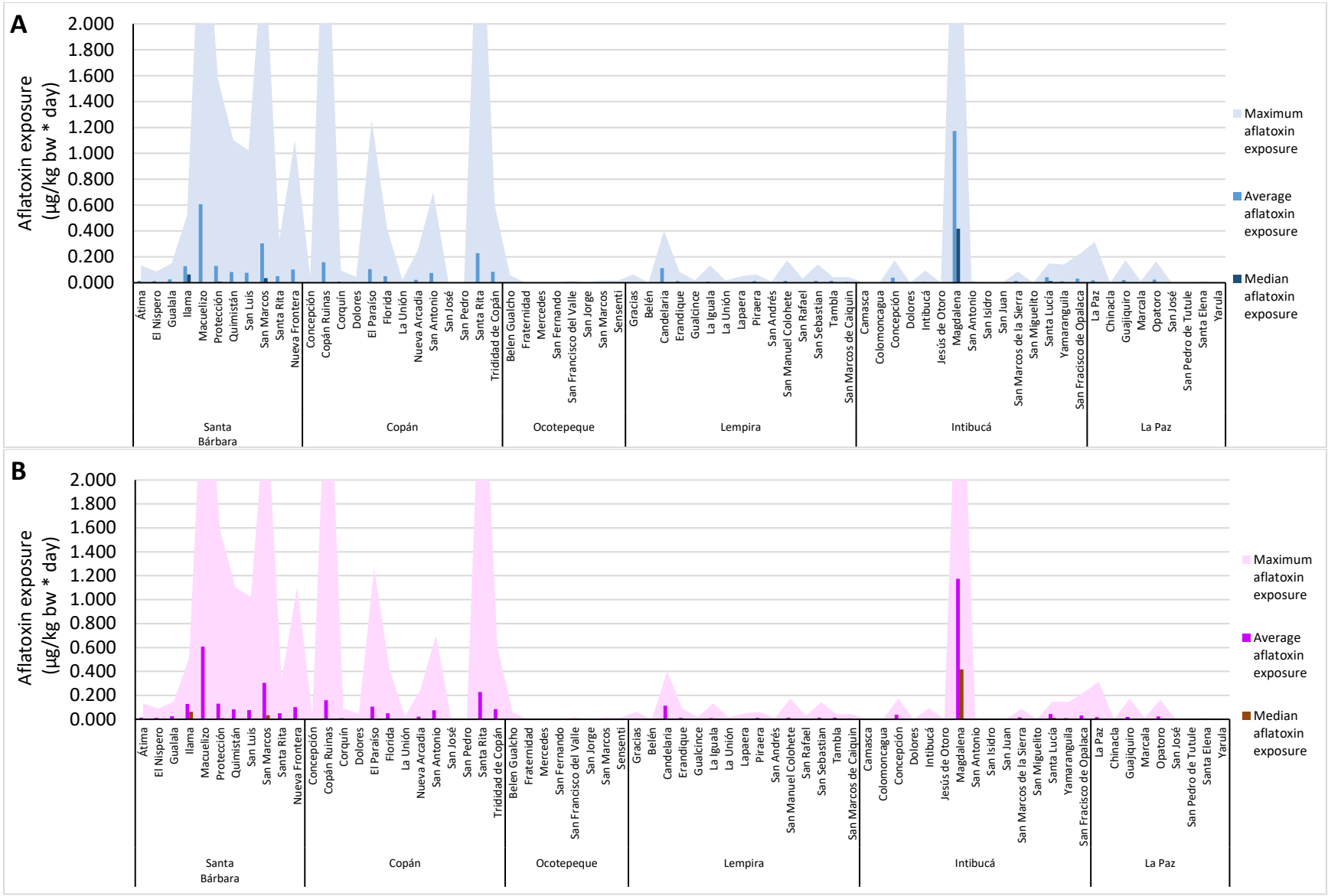


Figure 2.5.1 Summarized estimations of aflatoxin exposure for men (A) and women (B) of selected municipalities from Western Honduras – Corn season 2017-2018.

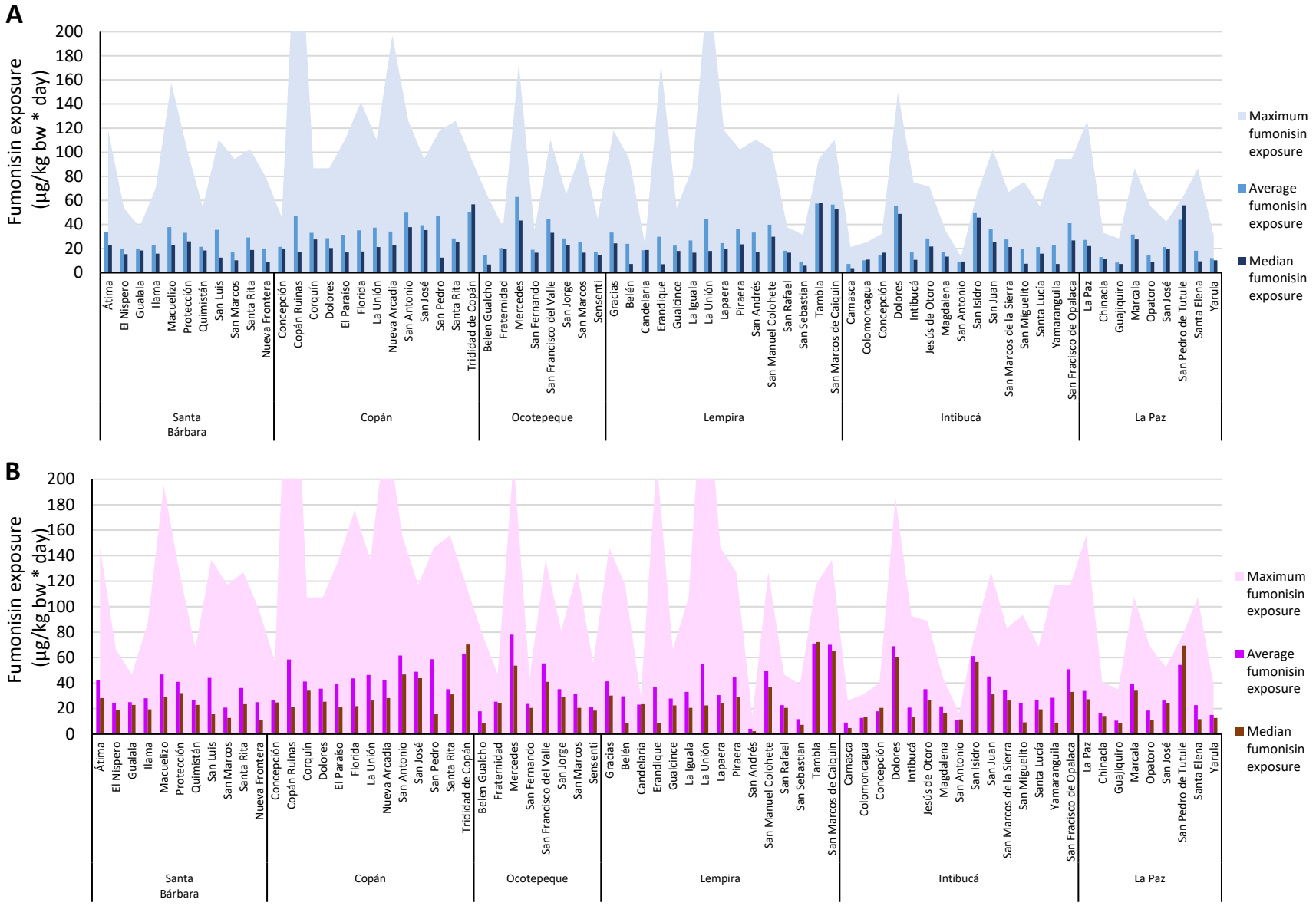


Figure 2.5.2 Summarized estimations of fumonisin exposure for men (A) and women (B) of selected municipalities from Western Honduras – Corn season 2017-2018.

2.5.5 References

1. Berthiller, F., C. Crews, C. Dall'Asta, S. De Saeger, G. Haesaert, P. Karlovsky, I. P. Oswald, W. Seefelder, G. Speijers, and J. Stroka. 2013. Masked mycotoxins: A review. *Mol. Nutr. Food Res.* 57:165–186.
2. Bressani, R. 1990. Chemistry, technology and nutritive value of maize tortillas. *Food Rev. Int.* 6:225–264.
3. Cornell University. 2015. Aflatoxins: Occurrence and Health Risks.
4. Dall'Erta, A., M. Cirlini, M. Dall'Asta, D. Del Rio, G. Galaverna, and C. Dall'Asta. 2013. Masked Mycotoxins Are Efficiently Hydrolyzed by Human Colonic Microbiota Releasing Their Aglycones. *Chem. Res. Toxicol.* 26:305–312.
5. Falavigna, C., M. Cirlini, G. Galaverna, and C. Dall'Asta. 2012. Masked fumonisins in processed food: co-occurrence of hidden and bound forms and their stability under digestive conditions. *World Mycotoxin J.* 5:325–334.
6. Gratz, S. W., R. Dinesh, T. Yoshinari, G. Holtrop, A. J. Richardson, G. Duncan, S. MacDonald, A. Lloyd, and J. Tarbin. 2017. Masked trichothecene and zearalenone mycotoxins withstand digestion and absorption in the upper GI tract but are efficiently hydrolyzed by human gut microbiota in vitro. *Mol. Nutr. Food Res.* 61:1–10.
7. Index Mundi. 2020. Honduras Corn Area Harvested by Year. *Agric. > Corn*.
8. Khlangwiset, P., G. S. Shephard, and F. Wu. 2011. Aflatoxins and growth impairment: A review. *Crit. Rev. Toxicol.* 41.
9. Magohaa, H., B. De Meulenaer, M. Kimanya, D. Hipolite, C. Lachat, and P. Kolsteren. 2014. Fumonisin B1 contamination in breast milk and its exposure in infants under 6 months of age in Rombo, Northern Tanzania. *Food Chem. Toxicol.* 74:112–116.
10. Magrine, I. C. O., S. S. C. Ferrari, G. F. Souza, L. Minamihara, C. Kemmelmeier, E. Bando, and M. Machinski. 2011. Intake of aflatoxins through the consumption of peanut products in Brazil. *Food Addit. Contam. Part B* 4:99–105.
11. Marshal, A.-L., D. J. Venuti, and D. J. Eastman. 2017. Fumonisin Exposure in Guatemalan Women of Child-Bearing Age: A Potential Link to the Observed High Incidence of Frontoethmoidal Encephalocele. *Ann. Glob. Heal.* Elsevier Inc.
12. Missmer, S. A., L. Suarez, M. Felkner, E. Wang, A. H. Merrill, K. J. Rothman, and K. A. Hendricks. 2006. Exposure to fumonisins and the occurence of neutral tube defects along the Texas-Mexico border. *Environ. Health Perspect.* 114:237–241.
13. Munkvold, G. P., S. Arias, I. Taschl, and C. Gruber-Dorninger. 2019. Mycotoxins in Corn: Occurrence, Impacts, and ManagementCorn, 3rd ed. Elsevier Inc.
14. Ohri-Vachaspati, P., and A. J. Swindale. 1999. Iron in the diets of rural Honduran women and children. *Ecol. Food Nutr.* 38:285–306.
15. Ono, E. Y. S., L. Biazon, M. Da Silva, É. Vizoni, Y. Sugiura, Y. Ueno, and E. Y. Hirooka. 2006. Fumonisins in corn: Correlation with *Fusarium* sp. count, damaged kernels, protein and lipid content. *Brazilian Arch. Biol. Technol.* 49:63–71.
16. Riley, R. T., O. Torres, J. Matute, S. G. Gregory, A. E. Ashley-Koch, J. L. Showker, T.

Mitchell, K. A. Voss, J. R. Maddox, and J. B. Gelineau-van Waes. 2015. Evidence for fumonisin inhibition of ceramide synthase in humans consuming maize-based foods and living in high exposure communities in Guatemala. *Mol. Nutr. Food Res.* 1:2209–2224.

17. Sadeghi, N., M. R. Oveisi, B. Jannat, M. Hajimahmoodi, H. Bonyani, and F. Jannat. 2009. Incidence of aflatoxin M1 in human breast milk in Tehran, Iran. *Food Control* 20:75–78.
18. Shephard, G. S. 2008. Impact of mycotoxins on human health in developing countries. *Food Addit. Contam. - Part A Chem. Anal. Control. Expo. Risk Assess.* 25:146–151.
19. Varga, J., N. Baranyi, M. Chandrasekaran, and C. Vágvölgyi. 2015. Mycotoxin producers in the *Aspergillus* genus: an update. *Acta Biol. Szeged.* 59:151–167.
20. Voth-Gaeddert, L. E., M. Stoker, O. Torres, and D. B. Oerther. 2018. Association of aflatoxin exposure and height-for-age among young children in Guatemala. *Int. J. Environ. Health Res.* Taylor & Francis 28:280–292.
21. WHO. 2015. Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Aflatoxin. 5639.
22. WHO. 2015. Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Fumonisin. 2–3.
23. Williams, J. H., T. D. Phillips, P. E. Jolly, J. K. Stiles, C. M. Jolly, and D. Aggarwal. 2004. Human aflatoxicosis in developing countries: A review of toxicology, exposure, potential health consequences, and interventions. *Am. J. Clin. Nutr.* 80:1106–1122.
24. WorldData. 2020. Average sizes of men and women. *Height. by Cont.*
25. Yazdanpanah, H., A. Zarghi, A. R. Shafaati, S. M. Foroutan, F. Aboul-Fathi, A. Khoddam, F. Nazari, and F. Shaki. 2013. Analysis of Aflatoxin B1 in Iranian Foods Using HPLC and a Monolithic Column and Estimation of its Dietary Intake. *Iran. J. Pharm. Res.* 12:81–87.
26. Zain, M. E. 2011. Impact of mycotoxins on humans and animals. *J. Saudi Chem. Soc.* King Saud University 15:129–144.

2.6 WHAT ARE SOME MITIGATING MEASURES THAT COULD BE EMPLOYED TO REDUCE MYCOTOXIN CONTAMINATION?

2.6.1 Background

Mycotoxins are considered significant food safety hazards, especially in the grain supply chain representing a major threat to human and animal health (*4*, *6*, *16*). Mycotoxin producing fungi are ubiquitous in nature and have adapted to a wide range of habitats ranging from temperate to tropical environments (*4*, *27*). When referring to the corn production chain, fungi can be classified into field fungi and storage fungi. Field fungi are able to invade grains during crop growth in the field prior to harvest. Some examples of genera under this classification include *Fusarium, Alternaria,* and *Cladosporium,* etc. Storage fungi contaminate grains during harvesting and predominate in grains during storage under favorable environmental conditions. Examples include *Aspergillus,* and *Penicillium*. Field fungi require high moisture levels (20-25 percent), whereas storage fungi are capable of growing at 13-18 percent grain moisture levels. Since contamination of cereal grains by fungal spores may not be completely avoided, mycotoxin producing fungi are present throughout the grain supply chain (*16*). Moreover, although a specific mycotoxin is produced as a by-product of certain fungal species (e.g. aflatoxins by *Aspergillus* species), in some cases a single fungal species is capable of producing more than one mycotoxin (e.g. zearalenone and deoxynivalenol by *Fusarium* species) (*16*).

Environmental factors such as grain type, nutritional composition, temperature, precipitation, humidity, biotic and abiotic stresses in plants, pH, water activity, carbon and nitrogen sources, plant metabolites etc. influence fungal spore germination, kernel infection, colony establishment and subsequent mycotoxin synthesis (*2*, *16*, *20*). Among all the above-mentioned factors, temperature and water activity are the most critical for successful mold growth and mycotoxin synthesis (*16*, *19*, *31*). Relative humidity (RH) is another important environmental factor affecting grain fungi and mycotoxin production during crop growth, storage and processing (*5*) as it influences the water activity in grains (*25*). In general, temperatures above 30°*C (86*°F*) and RH >70 percent for several days is conducive for mold growth and colony establishment (10).* Drought, nutrient deficiency, salinity stress, high-temperature stress, pest damage, mechanical damage, genotype, soil types, hot & high humidity etc. favors fungal contamination at the field level (*23*) whereas, damaged kernel, dust, moisture content of grain, temperature, relative humidity, pest activity etc. favors fungal contamination during grain storage (*24*, *30*). Additionally, the pre-harvest fungal infection greatly influences the fungal contamination and subsequent mycotoxin synthesis during post-harvest grain storage (*13*).

FAO estimates that about 500 million hectares around the world are dedicated to agriculture following traditional practices influenced by a combination of social, cultural, ecological and economic factors (*9*). Such handling practices may not effectively control pests and fungi. To address this, different avenues for controlling

mycotoxin contamination in the grain production chain can be explored: cultural control, host resistance, chemical control and biological control. Cultural control relies on modifications of a pest environment or habitat. Chemical control refers to the use of pesticides (i.e. insecticides, fungicides). Biological control implies the introduction of living microorganisms that decrease the pathogen of interest via nutrient depletion, predation or others.

At a field level, focusing on developing nations, cultural approaches can have promising results in a reduction of disease pressure due to their relative simplicity and low cost; some examples follow. As fungal spores are typically dispersed short distances, infections in a field commonly begin by spores within that field. A cultural practice to prevent this is the avoidance of monoculture. This can prevent the enrichment of soil with fungal spores, decreasing the likelihood for mycotoxin contamination in subsequent seasons. Another example is the timing of harvest. Generally, early harvesting results in lower concentrations of mycotoxins. Moreover, plants such as weeds can harbor a broad range of mycotoxigenic fungal species, thus their removal is recommended to avoid cross-contamination between hosts (*15*).

2.6.2 Evaluation Objective

To identify key mitigating strategies to reduce mycotoxin contamination in Honduras. Findings of this research can help gather more effective low-cost practices that inhabitants of the ZOI in Western Honduras can incorporate in their agricultural practices and grain handling to consume safe grain of high quality.

2.6.3 Methodology

Results of a multi-mycotoxin testing of fifty (32=producer, 18=marketer) corn samples collected from various municipalities across the ZOI were used in this assessment (See Question 2.2). Best practices to prevent or control the incidence mycotoxigenic fungi were addressed based on the identity of the corresponding taxa associated to corn (*i.e.,* fungal species capable of producing the detected toxins).

2.6.4 Key Findings

Table 2.6.1 Mycotoxigenic species of molds associated with mycotoxins found in small-scale study from Western Honduras. Corn season 2017-2018

Mycotoxin	Percentage of samples >LOD* (%)	Common mycotoxin producing taxa associated to corn	Reference
Aflatoxins Including types: B_1, B_2, G_1, and G_2	26.0	– *Aspergillus* species including *A. flavus, A. parasiticus*, and others.	(*16*, *35*)
Fumonisins Including types: B_1, B_2, B_3, B_4, and A_2	94.0	– *Fusarium* species including *F. verticillioides*, and *F. proliferatum*, among others. – *A. niger* – *Bipolaris maydis, B. sorokiana*	(*35*)
Trichothecenes Including: Nivalenol, Nivalenol Glucoside	64.0	– *Fusarium* species including *F. cerealis* and *F. poae*, among others.	(*39*)
Zearalenone and Zearalenone-sulfate	58.0	– *Fusarium* species including *F. graminearum* and *F. culmorum,* among others.	(*7*, *28*)
Citrinin	78.0	– *Penicillium* species, primarily *P. citrinum, P. expansum,* and *P. verrucosum*. – *Aspergillus* species such as *A. alabamensis*, *A. pseudoterreus*, and *A. niveus*, among others. – *Monascus purpureus*	(*35*)
Diplodiatoxin	82.0	– *Stenocarpella maydis*	(*38*)

∗LOD = Limit of detection. See Question 2 for detailed contamination levels and LOD information

While several organisms can synthesize the mycotoxins detected in the samples, their field management in some instances can be achieved with common good agricultural practices. Due to their association to corn, selected fungi are discussed below (further information, see Questions 2.1,2.2).

Fusarium is a common field fungus that attacks corn. *F. graminearum* can overwinter in crop debris or seed. Once environmental conditions are conducive, windborne spores are released. Seedlings can become infected at emergence. Vulnerable crops become most vulnerable during early flowering as pollen serve as a food source for this pathogen, affecting kernel formation (*37*). At later plant growth stages kernels can become infected through rain splash. If left untreated, infected seed will have poor germination. Infection of grains by *Fusarium* may also result in shrunken kernels.

Precipitation associated with air temperatures between 77-86°F accelerates disease development. While infected kernels may not show symptoms, they may still contain mycotoxins such as aflatoxin, deoxynivalenol and zearalenone (*3*, *18*). Similarly, *Fusarium verticillioides* is able to overwinter on infected plant debris as thickened hyphae in humid soil with poor aeration. Infection of corn may occur from late vegetative stages to three weeks after mid-silk (*37*). When conditions are permissive, hyphae germinate and infect germinating seed and roots, moving up the plant through systemic growth, as well as through the silk channel by airborne spores. Infection is enhanced by wet, warm weather following silking by 2-3 weeks, and damage to kernels by pests, hail, and other mechanical means. This fungus is also able to produce high levels of fumonisins at 59-77°F (*17*, *29*).

During later stages in the corn production chain, after harvest and where corn moisture levels have decreased, storage fungi thrive, and field fungi levels tend to decrease. While field fungi are no longer biologically active or present, any mycotoxins produced may persist in stored product. Two common storage fungi associated with corn are *Aspergillus* sp. and *Penicillium* sp.

Aspergillus is a competent saprophyte and can survive and colonize soil and organic debris associated with plant residues. When suitable environmental conditions arise, sclerotia and conidia germinate into mycelia, resulting in the release of spores into the air that can be available for colonizing neighboring corn plants. Ear rots can also be caused by the fungus *Aspergillus* that may infect wounded kernels and produces green-yellow spores. This is more commonly observed following hot, dry weather during the latter half of the growing season after pollination. Drought-stressed corn, such as that in non-irrigated fields are especially vulnerable to this fungus. Optimal conditions for fungal growth are 77-108°F, with optimum aflatoxin temperatures ranging from 81-86°F (*1*, *12*, *31*).

In the case of *Penicillium*, initial infection takes place predominantly on corn ears (i.e. in field, later in the season) that have been injured by mechanical means or insects. Later in harvest and during storage, powdery green or blue fungal growth becomes evident on kernels, most often at tip of the corn ear. Infected corn kernels may become bleached. *Penicillium* is a common storage fungus and can grow in corn at 18 percent moisture (*33*, *34*).

For proper disease management, low cost cultural approaches could include crop rotation, plant debris removal, and watering schedule, among others. Crop rotation fosters the exclusion of hosts such as wheat, barley and oats in between seasons to decrease inoculum during the following planting year (*37*). Controlling volunteer hosts to avoid early infections or performing tillage to bury infested residues below the soil surface also may reduce exposure of plant tissue to spores and destroy residue-borne inoculum. Irrigation (e.g. drip irrigation systems) could provide more efficient water

use, and irrigating during extended droughts would prevent plant stress. Moreover, suspending irrigation prior to flowering until after anthesis will reduce spore dissemination from in-crop residue.

Irrigation has been proved tremendously effective towards *Aspergillus* field management (*14*, *36*). This technique reduces plant stress through the avoidance of drought, consequently reducing the plant predisposition to infection and mycotoxin accumulation in the field. Moreover, timely applications of insecticides (e.g. lambda cyhalothrin, dimethoate) can help control corn earworms and European corn borers, decreasing entry points for non-endophytic fungi such as *Aspergillus* sp. For *Fusarium*, fungicides (e.g. prothioconazole), applying from silking to silk browning offers disease and mycotoxin suppression. Results are not conclusive towards *Aspergillus* control via fungicides, and thus some other avenues previously discussed should be explored. Corn varieties offering resistance to certain fungi are commercially available as adapted hybrids resistant to stalk rots and leaf blights. Varieties with spiraling rows, pointed tips, and looser husks, dry down faster and tend to be more resistant to fungal infection (*1*, *26*, *37*).

Crops should be harvested as soon as moisture levels allow, to avoid unnecessary injuries to kernels; drying should be to below 18 percent moisture for ears and 13-15 percent for shelled corn. A survey performed in the ZOI revealed that very few of the corn growers in the 6 departments evaluated (Figure 2.6.1) promptly harvest their corn within 100 days of being planted. The majority leave the corn plants in the field for an extended amount of time, between 101-150 days, with a substantial number (a majority, 41.7-91.4% during primera) surpassing 150 days. While the excess period in field may allow for the harvest to reach adequate moisture levels ca. 13 percent, it considerably increases vulnerable plant tissue to be exposed to pests and plant pathogens, including mycotoxigenic fungi, for a prolonged period thus increasing the possibility of fungal infestation and rise of mycotoxin contamination levels. Furthermore, it may take long for the moisture content to reach levels where mycotoxigenic fungi will not continue growing or producing mycotoxins; even though moisture content may eventually reach “acceptable” levels, toxins may have long since accumulated anyway.

Conversations with farmers revealed that the practice of leaving corn in the field is partly attributed to another commodity: coffee. According to the Honduran Institute of Coffee (IHCAFE), coffee harvesting in the ZOI takes place from December to March each year (*11*). Particularly for those corn growers who decide to plant corn in late *primera* and all *postrera*, their harvest coincides with that of coffee. In these cases, farmers give preference to coffee harvesting as both dates overlap, leaving corn harvest for last. This behavior is also accepted in the region and it ensures the corn to be dry whenever it is harvested, albeit with the noted mycotoxin risks.

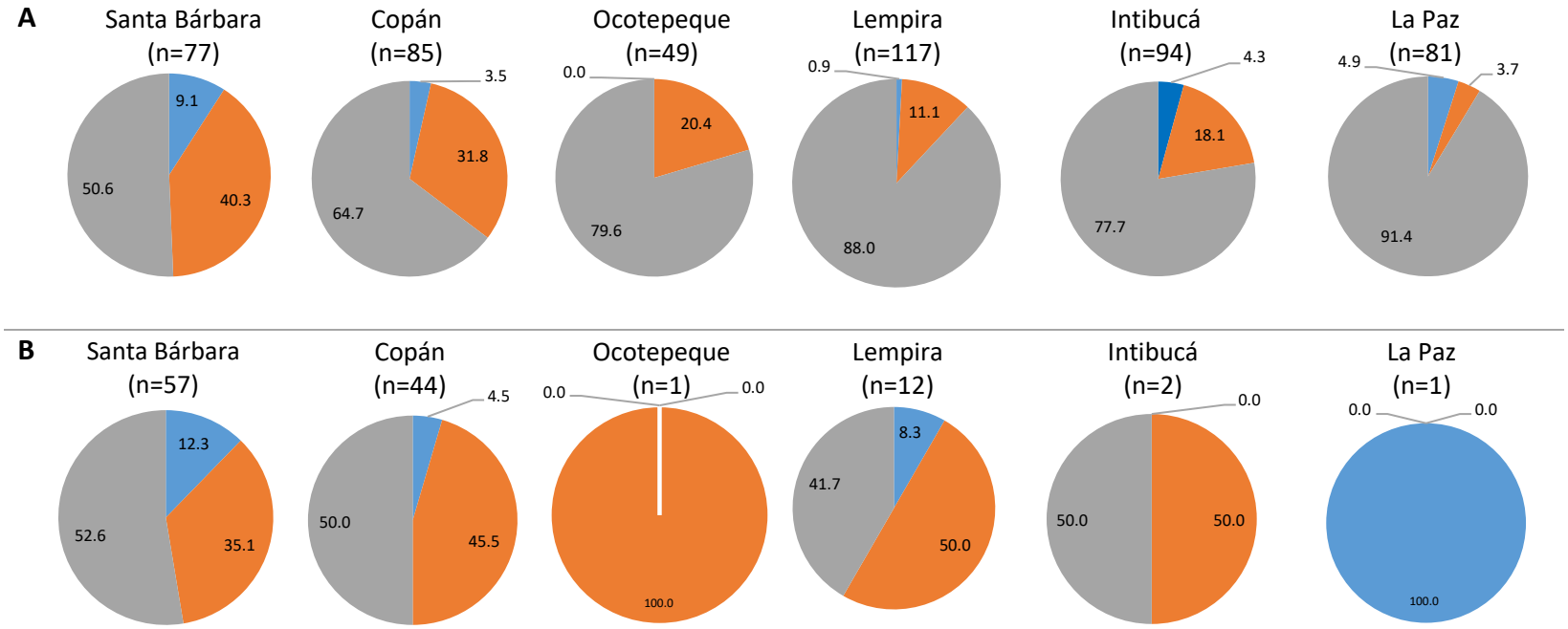


Figure 2.6.1 Corn plant period in field for Honduran growers. "Primera" period (A) corresponds to the percentage of farmers planting between months of April-August, and "postrera" period (B) to the percentage of farmers planting between September-January. Days in field from planting to harvesting ranges from 60-100 days (■), 101-150 days (■), and over 150 days (■). Number of responses per department denoted by *n*.

Furthermore, some farmers in Honduras already own solar dryers dedicated to coffee kernel drying (Figure 2.6.2). If corn harvesting is performed prior to the coffee harvest period, the existing infrastructure could be used to decrease the drying time of corn.

Figure 2.6.2 Example of coffee solar dryer located in the municipality Belén, Lempira, Honduras.

When placing the crops in storage, many corn growers and marketers rely on traditional vessels such as bags (sacos), trojas, and tapancos (See Question 2.4, Figure 2.4.1). Nonetheless, several growers (>20 percent overall), and mainly marketers from Lempira and Ocotepeque, own metal silos. When used properly, given the aerobic nature of fungi and other pests, the semi-hermeticism provided by metal silos allows for an extended period of storage, preserving quality and safety of the contents.

On a household level, presently, alkaline cooking or "nixtamalization" is widely used in Mexico and Central America to process corn. This thermal processing may or may not decrease the mycotoxin levels (several studies refer mainly to fumonisins and aflatoxins), particularly through partial solubilization of the metabolites, in some cases being a reversible phenomenon. For the removal of the solubilized fraction, this takes into consideration the elimination of the "nejayote" (liquid fraction of nixtamalization) (*8*, *21*, *22*). If Hondurans perform washes of the nixtamalized corn after the thermal treatment, this could decrease the toxin levels.

A lack of dietary diversity is directly related to a higher exposure to mycotoxins. In rural parts of Latin America, a high percentage of the caloric intake comes from corn, which is commonly contaminated with aflatoxins and/or fumonisins. Therefore,

access to a greater variety of foods will lower the risk of exposure by lessening the intake of this commonly contaminated staple grain *(40)*. Replacing foods at high risk for mycotoxin contamination with those at lower risk, would potentially lead not only to a higher intake of foods with better nutritional value, but also overall health of the population.

2.6.5 Relevance

Given the multi-toxin contamination detected in Honduran corn, mycotoxin synergistic effects are expected in the population of study, possibly being the culprit of (a multi-factorial nature for) different chronic diseases (e.g. renal disease) (*32*). Corn growers in the ZOI ought to change their field, storage and food preparation practices to decrease the levels of mycotoxin exposure.

For smallholder level farming, low cost cultural control practices are preferred as corn growers may not be able to incur in extra cost towards agricultural inputs. Cultural control strategies require little investment and represent minor changes in already existing farming practices.

Corn plants should remain in field for an adequate period to reach maturation with a timely harvesting process following. With the help of Honduran extensionists, encouraging farmers to modify their planting periods or varieties so that corn can be harvested before or after coffee is ready would avoid leaving corn in field for an extended time.

If feasible, acquiring or using existing drying technologies for other commodities can facilitate faster crop-drying to decrease fungal growth and subsequent toxin production. Suitable storage for grain that prevent pest access and oxygen/moisture exchange should be pursued; metal silos are an effective storage method that the Honduran population are acquainted with. Altogether, these practices can enable the Honduran corn handlers and consumers to obtain safer grain and maintain household food security as well as increase their marketability potential.

2.6.6 References

1. Abbas, H. K., J. R. Wilkinson, R. M. Zablotowicz, C. Accinelli, C. A. Abel, H. A. Bruns, and M. A. Weaver. 2009. Ecology of *Aspergillus flavus*, regulation of aflatoxin production, and management strategies to reduce aflatoxin contamination of corn. *Toxin Rev.* 28:142–153.
2. Bhatnagar, D., J. W. Cary, K. Ehrlich, J. Yu, and T. E. Cleveland. 2006. Understanding the genetics of regulation of aflatoxin production and *Aspergillus flavus* development. *Mycopathologia* 162:155–166.
3. Broders, K. D., P. E. Lipps, P. A. Paul, and A. E. Dorrance. 2007. Evaluation of *Fusarium graminearum* Associated with Corn and Soybean Seed and Seedling Disease in Ohio. *Plant Dis.* 91:1155–1160.

4. Bullerman, L. B. 1979. Significance of Mycotoxins to Food Safety and Human Health. *J. Food Prot.* 86:65–86.
5. Channaiah, L. H., and D. E. Maier. 2014. Best Stored Maize Management Practices for the Prevention of Mycotoxin Contamination, p. 78–89. *In* A.F. Logrieco, and J.F. Leslie (eds.), Mycotoxin Reduction in Grain Chains. John Wiley & Sons, Ltd, Hoboken, NJ, USA.
6. Cole, R. J., and R. . Cox. 1981. Handbook of Toxic Fungal Metabolites. Academic Press, New York.
7. Döll, S., and S. Dänicke. 2011. The *Fusarium* toxins deoxynivalenol (DON) and zearalenone (ZON) in animal feeding. *Prev. Vet. Med.* Elsevier B.V. 102:132–145.
8. Dombrink-Kurtzman, M. A., T. J. Dvorak, M. E. Barron, and L. W. Rooney. 2000. Effect of nixtamalization (alkaline cooking) on fumonisin-contaminated corn for production of masa and tortillas. *J. Agric. Food Chem.* 48:5781–5787.
9. FAO. 2015. Accenting the "culture" in agriculture. *-In action- stories Arch.*
10. Grain Inspection, P. and S. A. (GIPSA). 2006. Grain Fungal Diseases & Mycotoxin Reference. Washington, D.C.
11. Instituto Hondureño del Café (IHC). 2020. Regiones cafetaleras de Honduras. *IHCAFE*.
12. Jackson-Ziems, T. A. 2016. Ear and Stalk Rot Diseases Becoming More Common in Corn Fields. *Crop. UNL*.
13. Jaime-Garcia, R., and P. J. Cotty. 2003. Aflatoxin contamination of commercial cottonseed in South Texas. *Phytopathology* 93:1190–1200.
14. Jones, R. K., H. E. Duncan, and P. B. Hamilton. 1981. Planting date, harvest date, irrigation effects on infection and aflatoxin production by *Aspergillus flavus* in field corn. *Ecol. Epidemiol.* 71:810–816.
15. Jouany, J. P. 2007. Methods for preventing, decontaminating and minimizing the toxicity of mycotoxins in feeds. *Anim. Feed Sci. Technol.* 137:342–362.
16. Lee, H. J., and D. Ryu. 2017. Worldwide Occurrence of Mycotoxins in Cereals and Cereal-Derived Food Products: Public Health Perspectives of Their Co-occurrence. *J. Agric. Food Chem.* 65:7034–7051.
17. Leslie, J. F., and B. A. Summerell. 2006. The *Fusarium* Laboratory Manual. Blackwell publishing.
18. Liu, B., L. J. Giesler, T. A. Jackson-Ziems, S. N. Wegulo, R. M. Harveson, K. A. Korus, and R. N. Klein. 2012. Major *Fusarium* Diseases on Corn, Wheat, and Soybeans in Nebraska. *Nebraska Ext. G2181*.
19. Mannaa, M., and K. D. Kim. 2017. Influence of temperature and water activity on deleterious fungi and mycotoxin production during grain storage. *Mycobiology* 45:240–254.
20. Medina, A., A. Rodriguez, and N. Magan. 2014. Effect of climate change on *Aspergillus flavus* and aflatoxin B 1 production. *Front. Microbiol.* 5:1–7.
21. Méndez-Albores, J. A., G. Arámbula-Villa, M. G. Loarca-Piña, J. González-Hernández, E. Castaño-Tostado, and E. Moreno-Martínez. 2004. Aflatoxins' fate during the nixtamalization of contaminated maize by two tortilla-making processes. *J. Stored Prod. Res.* 40:87–94.

22. Méndez-Albores, J. A., G. A. Villa, J. C. Del Rio-García, and E. M. Martínez. 2004. Aflatoxin-detoxification achieved with Mexican traditional nixtamalization process (MTNP) is reversible. *J. Sci. Food Agric.* 84:1611–1614.
23. Milani, J. M. 2013. Ecological conditions affecting mycotoxin production in cereals: A review. *Vet. Med. (Praha).* 58:405–411.
24. Miller, J. D. 1995. Fungi and Mycotoxins in Grain: Implications for Stored Product Research. *J. Stored Prod. Res.* 31:1–16.
25. Northolt, M., and L. B. Bullerman. 1982. Prevention of Mold Growth and Toxin Production through Control of Environmental Conditions. *J. Food Prot.* 45:519–526.
26. Patrick Porter, E. Bynum, R. D. Parker, R. Bowling, and S. P. Biles. 2016. Managing insects and mite pests of Texan corn. *Texas A&M Agrilife Extension. ENTO-0492/16*.
27. Purchase, I. F. H. 1971. Symposium of mycotoxins in human health, 1st ed. Macmillan, London, UK.
28. Richard, E., N. Heutte, L. Sage, D. Pottier, V. Bouchart, P. Lebailly, and D. Garon. 2007. Toxigenic fungi and mycotoxins in mature corn silage. *Food Chem. Toxicol.* 45:2420–2425.
29. Samapundo, S., F. Devlieghere, B. De Meulenaer, A. H. Geeraerd, J. F. Van Impe, and J. M. Debevere. 2005. Predictive modelling of the individual and combined effect of water activity and temperature on the radial growth of *Fusarium* verticilliodes and F-proliferatum on corn. *Int. J. Food Microbiol.* 105:35–52.
30. Sanchis, V., and N. Magan. 2004. Environmental conditions affecting mycotoxins, p. 174–189. *In* M. Olsen (ed.), Myotoxins in foods. Woodhead Publishing Ltd, Cambridge.
31. Schmidt-Heydt, M., C. E. Rüfer, A. Abdel-Hadi, N. Magan, and R. Geisen. 2010. The production of aflatoxin B1 or G1 by *Aspergillus parasiticus* at various combinations of temperature and water activity is related to the ratio of aflS to aflR expression. *Mycotoxin Res.* 26:241–246.
32. Speijers, G. J. A., and M. H. M. Speijers. 2004. Combined toxic effects of mycotoxins. *Toxicol. Lett.* 153:91–98.
33. Su-lin L. Leong. 2012. Microbial populations during maize storage in Cameroon. *African J. Biotechnol.* 11:8692–8697.
34. University of Illinois Extension. 2020. *Penicillium* Ear Rot. *Ext. Outreach*.
35. Varga, J., N. Baranyi, M. Chandrasekaran, and C. Vágvölgyi. 2015. Mycotoxin producers in the *Aspergillus* genus: an update. *Acta Biol. Szeged.* 59:151–167.
36. Waliyar, F., A. Traore, D. Fatondji, and B. R. Ntare. 2003. Effect of Irrigation Interval, Planting Date, and Cultivar on *Aspergillus flavus* and Aflatoxin Contamination of Peanut in a Sandy Soil of Niger. *Peanut Sci.* 30:79–84.
37. White, D. G. 2010. Compendium of Corn Diseases, 3rd ed. The American Phytopathological Society Press, Urbana-Champaign.
38. Wicklow, D. T., K. D. Rogers, P. F. Dowd, and J. B. Gloer. 2011. Bioactive metabolites from Stenocarpella maydis, a stalk and ear rot pathogen of maize. *Fungal Biol.* Elsevier Ltd 115:133–142.

39. Yazar, S., and G. Z. Omurtag. 2008. Fumonisins, trichothecenes and zearalenone in cereals. *Int. J. Mol. Sci.* 9:2062–2090.
40. Groopman J., Kensler T., and Wild C. 2008. Protective interventions to prevent aflatoxin-induced carcinogenesis in developing countries. *Annu. Rev. Public. Health*. 29(1):187–203.

2.7 HOW DOES GENDER (OR FEMALE EMPOWERMENT) INFLUENCE THE ABILITY TO MITIGATE EXPOSURE TO MYCOTOXINS AND TO ADOPT TECHNOLOGIES AND PRACTICES FOR MYCOTOXIN MANAGEMENT?

2.7.1 Background

The economy of Honduras is based mainly on agriculture, which accounted for approximately 12 percent of its gross domestic product (GDP) in 2018 (*9*). Statistics from FAO reveal that 66 percent of Honduran farmers have access to only 8 percent of all cultivable land in the country, and from these women comprise only 4 percent of the beneficiaries of land. Women's plots also tend to be very small (*3*). The agricultural sector currently faces challenges such as climate change, economic inequality, and the high migration rates in search of better opportunities leave gaps in the workforce for the Honduran rural sector. Therefore, the pursuit of strategies to increase productivity, improve competitiveness and make more sustainable use of the country's resources is increasingly important. Women and youth in Honduras could represent agents of change to alleviate the agrarian rural sector situation in Honduras (*8*).

Honduran women play an important part in agriculture, particularly in smallholder farming, working an average of four hours a day in crop and livestock activities. On a household level, approximately 20 percent of rural households are led by women, including farming production (*4*). Moreover, in households with farming activities where both men and women are present, both sides often share the decision-making such as germplasm selection. Men predominate in decisions regarding type of crops to be planted, and other agricultural inputs such as fertilizer usage, while women are primarily involved in family expenses and pricing of produce (*4*, *6*). Across the developing world, the labor burden of women in rural areas exceeds that of men and includes a higher proportion of unpaid household responsibilities related to preparing food and collecting fuel and water. The contribution of women to agricultural and food production is significant but it is difficult to verify the share produced by women (*2*) (Table 2.7.1). A study in agroforestry and Honduran women by Wiff (*11*) showed similar hurdles and outcomes. Changes should be community- and stakeholder-informed, and co-created, and deployed with short-, medium- and longer-term intervention strategies. Furthermore, Honduran women in rural areas are unaware of their own ability to cooperate in development, their involvement may be very limited, however they represent half of the country's human resources to achieve a change in current activities, such as poor agricultural practices.

Table 2.7.1 Honduran evolution of the rural economically active population by sex, 1980-2000**.** Adapted: (*1*)

	Rural economic activity rates (per 100 population aged 10 and over)						
Gender	1980	1985	1990	1995	2000	2005 (projected)	1980-2000 (% change)
Males	81	82	82	81	81	80	-0.94
Females	8	10	11	14	16	19	104.07

2.7.2 Evaluation Objective

Determine crucial mycotoxin mitigation strategies where the involvement of Honduran women is key to achieve effective mycotoxin management. Outcomes of this research can help foster the female role as leaders of the ZOI to improve the livelihoods of Hondurans when facing household consumption of food groups susceptible to mycotoxin contamination.

2.7.3 Methodology

Selected results of a survey carried out in the ZOI addressed to corn growers (see Question 2.4). Results were combined with current knowledge of gender roles in agricultural activities taking place in Honduras to identify critical mitigation strategies for mycotoxin control, focusing primarily on roles by Honduran women.

2.7.4 Key Findings

Incorporating women in agricultural activities requires equal access to information, which is currently lacking in the country. A small scale study on Honduran women by Meir (*5*), while focused on pest management, points out several constraints that must be addressed in order to effectively empower women in agricultural activities. The lack of representation in agricultural activities could be attributed to men focusing on outside interest thus, invitations to training courses typically go almost exclusively to men. Moreover, commonly held trainings require trainees to be literate, and with the literacy rate among rural women being lower than that of men, this results in exclusion of women; tools and approaches are available that can effectively train illiterate participants, including the manual produced in PHLIL Guatemala, as well as videos from Scientific Animations Without Borders, which also include PHLIL mycotoxin topics. Another hurdle women face in Honduras is the lack of childcare for them to attend training. In most households, men are seen as authority figures and in some cases, they do not grant permission to participate in training. This study also showed that implementation of acquired knowledge for women who owned/ controlled land themselves was likely to take place. However, on family plots largely controlled by men, contributing women are less empowered.

Selected results from the survey carried out in the ZOI (Figures 2.7.1 and 2.7.2) show current deficiencies regarding agricultural activities, all of which women can have an active role to lessen the burden of losses every season. When corn growers from Honduras were asked about their frequency of grain inspection in storage, close to 20 percent across the departments reported not having any. Similarly, their perception of the main reasons of corn losses from harvest to the final consumption (Figure 2.7.2) revealed inadequate drying and pests as the main perceived spoilage causes. Given that the activities of drying of grain prior to storage and inspection prior to consumption end with the starting material for food preparation, an activity well known belonging to women, it would be beneficial to incorporate female family members in early stages soon after harvest so that they understand which practices (e.g. selection) will result in the best quality food starting material.

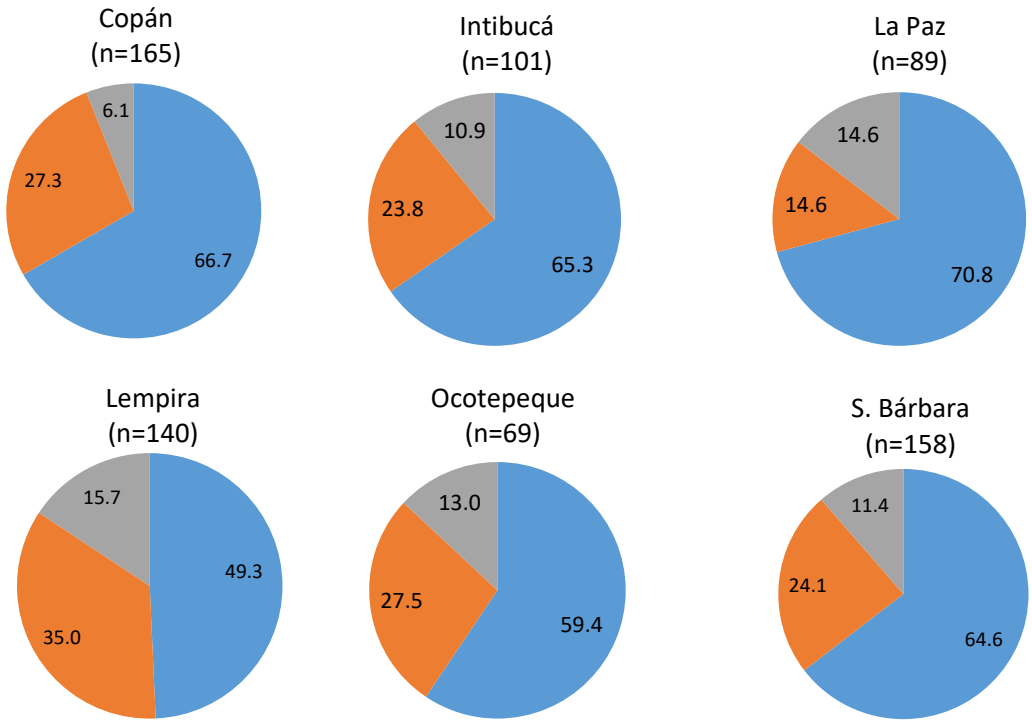


Figure 2.7.1 Departmental frequency of corn quality inspections during storage in western Honduras**.** Legend: Yes (■), No (■), Do not know/No response (■). Number of responses per department denoted by *n*.

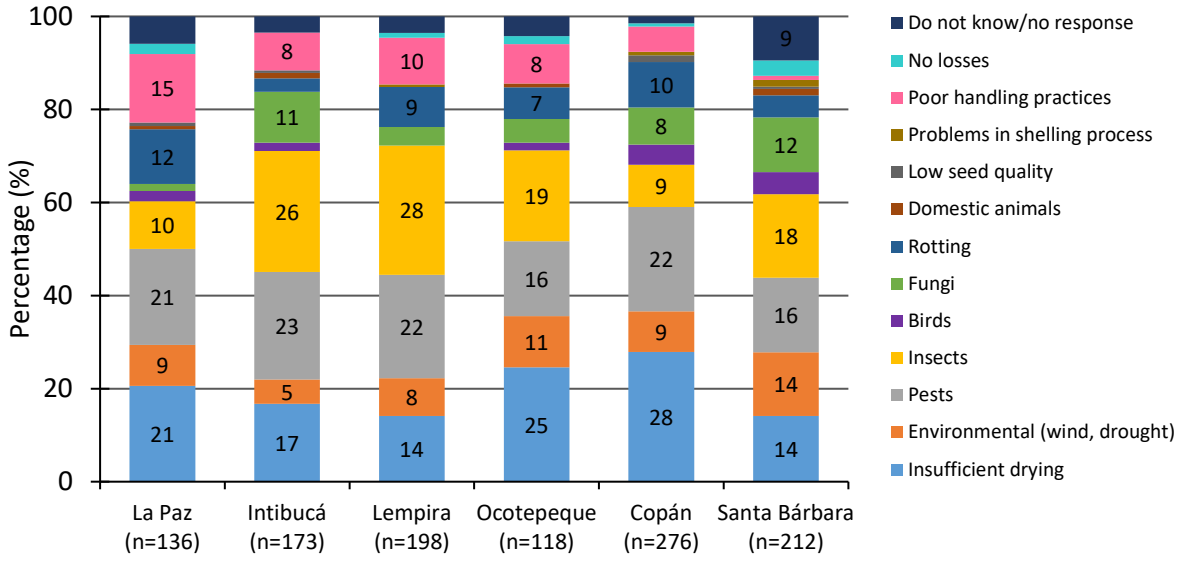


Figure 2.7.2 Factors perceived by farmers to be contributing to corn loses in Western Honduras**.** Number of responses per department denoted by *n*. Not all numeric values for percentages are shown on the graph and the total value of each column is equal to 100 percent.

Presently, Davis (*1*) explains that the changing roles of women and men in the Latin American rural economy are owed to social and economic trends over the past 30 years, pushing women to participate more visibly in their households' livelihood strategies. Rural women are more highly educated and are having fewer children than they were 20 years ago, allowing them with time to join the rural workforce.

Pushing out of the patriarchal nature of Latin American society, Rowlands (*7*) suggest following the Womankind World-wide empowerment criteria, depicted in Figure 2.7.3. The development of straightforward training platforms, exclusively directed towards women and youth, ought to be considered. With the help of Honduran NGOs, extensionists, and microfinance institutions, offering trainings around grain handling practices integrating gender equity, can help promote women empowerment and positive involvement in the corn production chain.

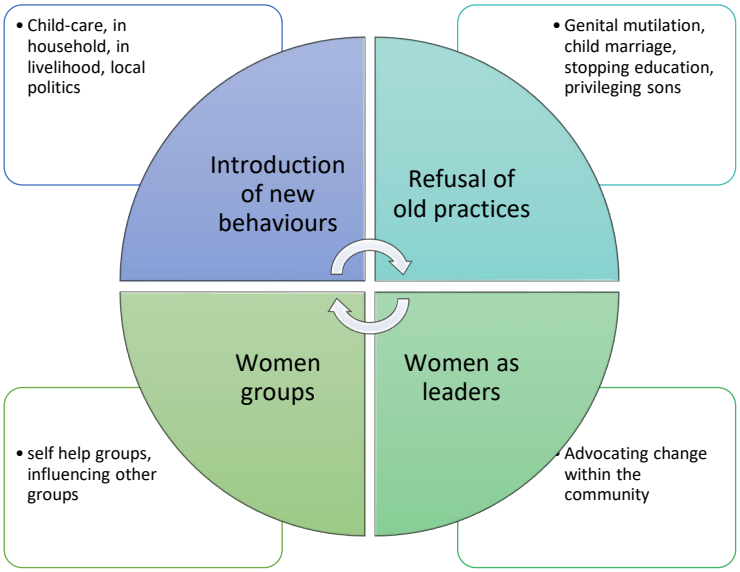


Figure 2.7.3 Empowerment criteria for Honduran women in agriculture. Adapted from Rowlands (7).

Approaches taking multi-sectorial support/involvement that have succeeded in Honduras include the United Nations Development Programme's "Human Development for Youth: Overcoming the Challenges of Migration through Employment" (*10*), which is improving livelihoods of Honduran women and fostering gender awareness. Moreover, the role of women in agriculture has also been investigated by PHLIL in the neighboring country of Guatemala. With the consultation of a Guatemalan gender specialist, Ada Rocina Chavarría, a multifaceted manual covering grain handling practices and proper nutrition deployed in the Western Highlands of Guatemala incorporates notes of gender equality for proper incorporation of women throughout the corn production chain. Emphasis was placed on the nutritional section on how a diverse diet with

the inclusion of meats and vegetables was beneficial for the health of the household, effectively diluting the ingestion of possibly contaminated grain. An example is depicted on Figure 2.7.4.

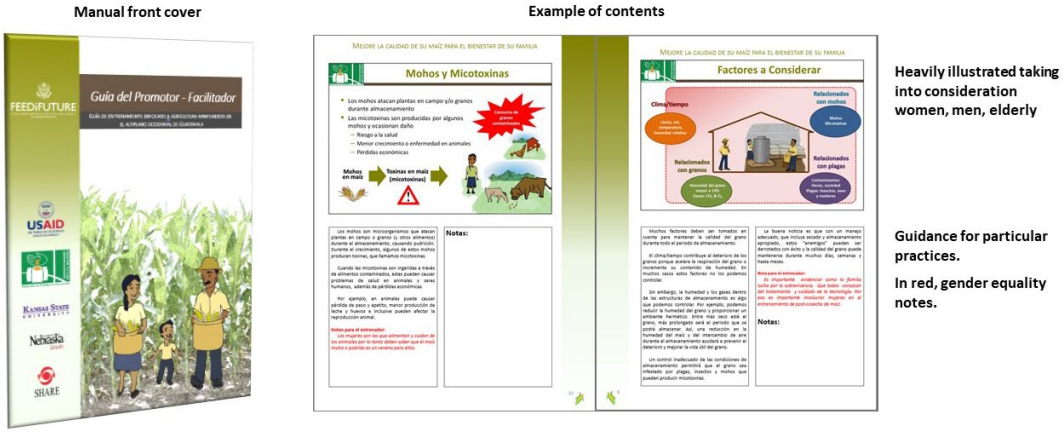


Figure 2.7.4 Portion of Guatemalan smallholder manual promoting gender equality. Product of the Feed the Future Innovation Lab for the Reduction of Post-Harvest Loss.

For Honduran women to understand the importance a diversified diet has on decreasing daily mycotoxin exposure can benefit the livelihoods of Hondurans. Women typically have the role of food preparation in the household, thus by being aware of the risks of a grain-based diet, particularly with inputs of poor quality, they can decide what to feed their household.

2.7.5 References

1. Davis, B. 2003. Food, Agriculture, and Rural Development: Current and Emerging Issues for Economic Analysis and Policy Research (CUREMIS II). FAO, Rome.
2. Doss, C., T. Raney, G. Anríquez, A. Croppenstedt, S. Gerosa, S. Lowder, I. Matuscke, and J. Skoet. 2011. The Role of Women in Agriculture. *ESA Work. Pap. No. 11-02 . Agric. Dev. Econ. Div.*
3. FAO. 1993. Access to agricultural resources and services. *Secr. Nat. Resour. Ext. Staff by position Gend.*
4. FAO. Role of women in agriculture. *Div. Labour by Gend.*
5. Meir, C. J. 1999. Improving women's participation in pest management training: a pilot study in Honduras, p. 59–70. *In* E. van de Fliert, and J. Poost (eds.), Women and IPM. Crop protection practices and strategies. Intermediate Technology Publications, London, UK.
6. Rosas-Sotomayor, J. C., O. Gallardo-Guzmán, and J. Jiménez-Torres. 2006. Mejoramiento de maíces criollos de honduras mediante la aplicación de metodologías de fitomejoramiento participativo. *Agron. Mesoam.* 17:383–392.
7. Rowlands, J. 1997. Questioning Empowerment: Working with Women in Honduras. Oxfam, UK.
8. Stockholm Environment Institute (SEI). 2019. Harnessing the power of women

and youth in Honduras rural development. *L. Food Agric.*

9. Trading Economics. 2020. Honduras - Agriculture, Value Added (% Of GDP). *Honduras | Econ. Growth*.
10. United Nations. 2013. Honduras: women finding their way. *Adv. Gend. Equal. Promis. Pract.*
11. Wiff, M. 2012. Honduras: Women make a start in agroforestry. *Unasylva 146*. FAO.

3. REPORTING ON REQUIRED TASKS

3.1 DESIGN A RESEARCH AND SAMPLING METHODOLOGY. *The PHL Innovation Lab, prior to inception of field activities, will develop the approach and methodology for conducting the assessment basing it on international best practices and standards.*

The sampling design was developed by the PHL Innovation Lab in consultation with the USAID Mission in Honduras, Zamorano University and other in-country collaborators. A detailed description of the criteria used for sample inclusion can be found in this document under the "Assessment Questions", more specifically under the Methodology description for Question 2.1.

Several iterations of the sampling design were considered based on the feedback provided by all the collaborators. An overview of the final sampling design is presented in Figure 3.1.1, where it details information used for sample selection: Department, Municipality, Area and Community. A total expected number of samples is included, and when samples meeting the established criteria were available those samples were collected according to established methodology. Please refer to the "Assessment Questions" section of this document for further details on methodology used for sample collection, storage and transportation to the research laboratory.

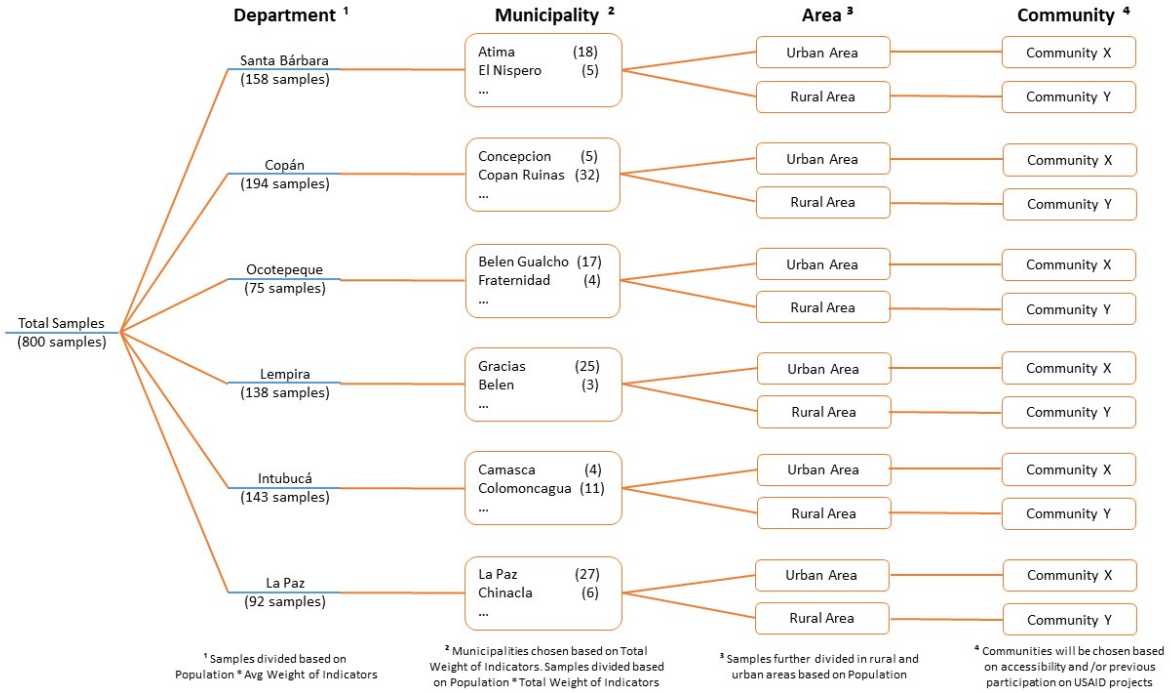


Figure 3.1.1 Sampling design and sample distribution among departments, municipalities, areas and communities included in the mycotoxin assessment in the dry corridor of Honduras.

Before any samples were analyzed by the laboratory at Zamorano University, the method to be used for mycotoxin quantification was determined. Among the commercially available rapid methods, three were chosen to be evaluated: Romer Labs *AgraQuant®*, Neogen Veratox®, and Vicam fluorometric method (*Method 4.4 Corn, raw peanuts, and peanut butter using AOAC method* for aflatoxins and *4.2 Fumonitest fluorometer procedure for corn and milo* for fumonsin). All methods were tested for the quantification of both total aflatoxins (B_1, B_2, G_1, and G_2) and total fumonisins (B_1, B_2, and B_3). The method evaluation was done using reference material contaminated with either aflatoxin or fumonisin at known levels, and included contamination at low, medium and high levels. Reference material was sourced from Romer Labs (Biopure™) and Trilogy Analytical Laboratory. The mycotoxin quantification methods were carried out according to the manufacturer's instructions for each of the tests used over a period of 5 days. Tests were replicated by several highly trained technicians. The results obtained for different brands of reference materials at different levels of contamination were then used to determined which method provided the most consistent results. An example of the results obtained is shown in Figure 3.1.2, where the confidence intervals for one, two and three standard deviations are also displayed. These intervals of confidence were determined based on the toxin information (average and standard deviation values) provided by the supplier for each reference material.

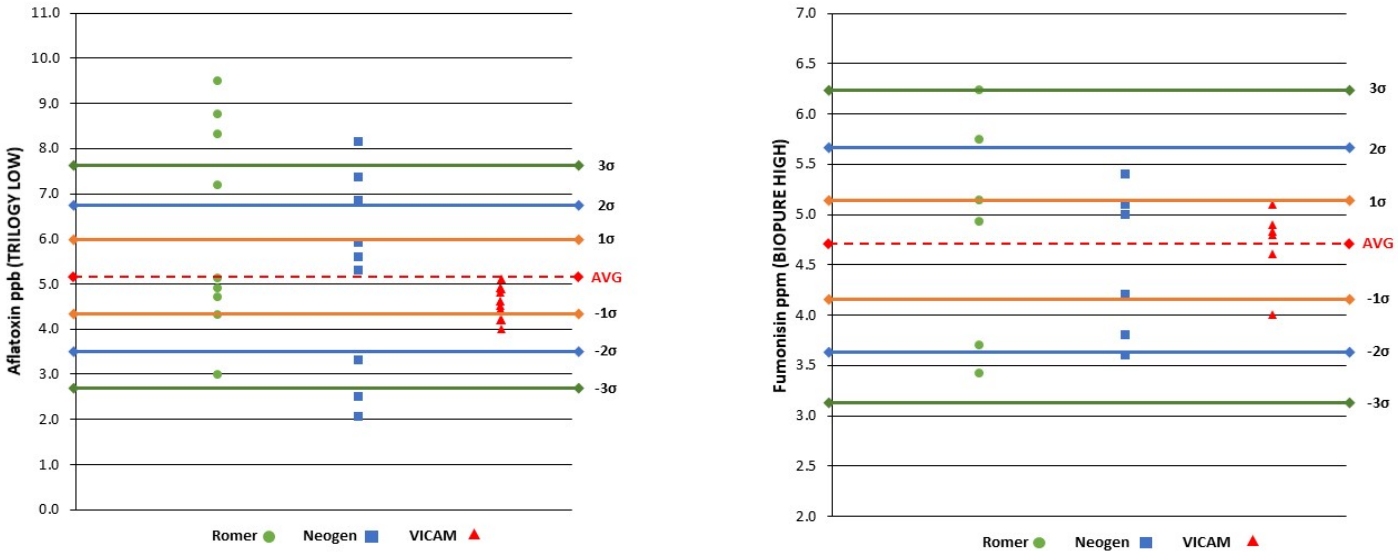


Figure 3.1.2 Mycotoxin quantification by three rapid methods (Romer, Neogen and Vicam) for aflatoxin reference material contaminated with low levels of toxin, and for fumonisin reference material contaminated with high levels of toxin.

Based on the results obtained, and as illustrated in Figure 3.1.2, the most consistent results were obtained with the fluorometric method by Vicam, which consistently showed less variation among the results, regardless of the technician running the samples, the

supplier of the reference material, the toxin under evaluation and the level of toxin in the reference material. Therefore, the Vicam method, consisting of sample extract clean up by immunoaffinity column and toxin detection by fluorometry was the chosen methodology for the quantification of mycotoxin in all samples collected as part of the assessment in Honduras. Notably, this is the most versatile analysis method, enabling Zamorano University to analyze a broad range of commodities/matrices in the future.

After choosing the method, an additional evaluation was done based on the ability of the method to recover mycotoxin spiked into ground corn samples that were originally free of mycotoxins. Therefore, recovery studies were conducted by spiking blank ground corn samples with a mixture of aflatoxin (34036, Milipore Sigma) or fumonisin B_1 (F1147, Milipore Sigma) standards at spiking levels above the limit of detection (LOD) of the equipment used (LOD: 1 µg/Kg for aflatoxin and 0.25 mg/Kg for fumonisin). Recoveries (RE) were calculated using equation 3.1.1 are reported in Table 3.1.1. Mycotoxin recoveries found between 80 to 110 percent were considered adequate (*1*, *2*) and the methods implemented for mycotoxin detection in corn samples collected as part of the mycotoxin assessment in Honduras.

$$\mathrm{RE} = \left(\frac{\text{Mycotoxin content in spiked blank sample}}{\text{Theoretical mycotoxin content}}\right) * 100\% \quad \textbf{Eq. 3. 1. 1}$$

Table 3.1.1 Aflatoxin and fumonisin recoveries in ground corn.

Mycotoxin (spiking level)	**Extract**	**Reading**	**Average ± SD**	**Recovery (percent)**
Aflatoxin (10 µg/Kg)	1	8.2	8.4 ± 0.3	84.0
	2	8.2		
	3	8.1		
	4	8.6		
	5	8.9		
Fumonisin (0.5 mg/Kg)	1	0.7	0.5 ± 0.3	95.5
	2	0.5		
	3	0.2		

References

1. AOAC International. 2002. AOAC Guidelines for Single Laboratory Validation of Chemical Methods for Dietary Supplements and Botanicals.
2. Codex Alimentarius. 2019. CODEX General Standard for Contaminants and Toxins in Food and Feed. CODEX STAN 193-1995.

3.2 TRAIN TECHNICIANS. *The PHL Innovation Lab will hire, if necessary, and train an appropriate number of technicians on how to properly collect, store, and transport corn samples from the field to the university where analysis will be done.*

Before sample collection was started, all field technicians supporting the mycotoxin assessment in Honduras were trained in how to properly collect the samples and how to prepare them for shipment to ensure sample representativeness and integrity. According to Whitaker and others (*2*), mycotoxins occur in such a way that they are unevenly distributed in grains, therefore high concentrations of toxins can be found in "hot spots" or "pockets" either in bulk grain or in the field. This uneven distribution contributes to total error in mycotoxin results (Figure 3.2.1). Efforts were made to train the technicians recruited for the mycotoxin assessment in Honduras to as much as possible reduce the error attributed to sample collection.

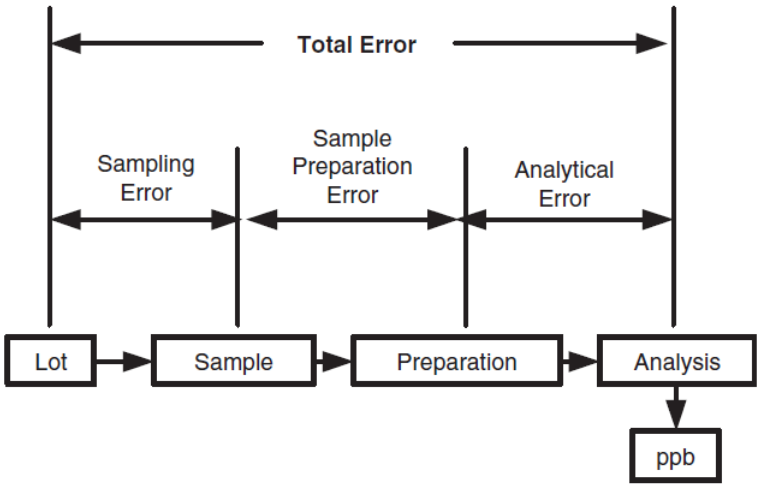


Figure 3.2.1 The total error of the mycotoxin test procedure is the sum of sampling, sample preparation and analytical errors. Copied from Whitaker (1).

Training materials were prepared about the theory of appropriate sampling, along with activities that demonstrate good sampling practices. The training also included an overview about mycotoxins, including their source and potential health effects. The information was then shared with technicians in a series of workshops in several locations throughout the dry-corridor. Table 3.2.1 shows the location of each training, the number of participants and the date when the training occurred. Figures 3.2.2 and 3.2.3 show pictures of the training in two locations: La Paz and Ocotepeque, respectively.

Table 3.2.1 Location, date and number of technicians (males and females) trained in corn sampling for mycotoxin analysis.

Location and Date	Males	Females	Total
Copán – November 7, 2017	40	1	41
Intibucá – November 10, 2017	50	2	52
La Paz – November 10, 2017	24	3	27
Lempira – November 9, 2017	33	2	35
Ocotepeque – November 8, 2017	35	4	39
Santa Bárbara – November 6, 2017	36	2	38
(Total Numbers)	**218**	**14**	**232**

Note: given that the technicians invited to the training were already those working with Fintrac, PHLIL was engaging a pre-existing network of technicians, and had limited influence on the gender balance ratio.

Figure 3.2.2 Picture of the training for field technicians in La Paz, November 10th, 2017.

Figure 3.2.3 Picture of the training for field technicians in Ocotepeque, November 8th, 2017.

As described in Table 3.2.1, a total of 232 technicians (218 males and 14 females) were trained in proper sample collection for mycotoxin analysis. Once trained, technicians were encouraged to start the sampling process, following the Standard Operation Procedures (SOPs) developed for this assessment. SOPs were created for sample collection, evaluation at the field level, aggregation, transportation, and receiving at the laboratory to ensure traceability and complete data collection.

In addition to the training required for sample collection, all the materials and equipment to be utilized during sample collection and storage prior to shipment to the laboratory for analysis were provided. A total of 12 portable grain moisture testers (Dickey John), 60 sampling probes (40" brass open handle with 6 openings – Seedburo) and 12 horizontal freezers were provided to the team collecting samples in the field. Any disposable materials (i.e. sample bags) needed were also provided.

The sample collection period expanded from November 2017 until October 2018, and during that period a total of 872 samples of corn were collected, transported and delivered at the laboratory at Zamorano University for mycotoxin analysis.

References:

1. Whitaker, T. B. 2006. Sampling foods for mycotoxins. *Food Addit. Contam.* 23:50–61.
2. Whitaker, T. B., A. B. Slate, M. B. Doko, B. M. Maestroni, and A. Cannavan. 2010. Sampling procedures to detect mycotoxins in agricultural commodities. Springer, London, UK.

3.3 PROVIDE TECHNICAL, EQUIPMENT, AND MATERIAL SUPPORT TO ZAMORANO UNIVERSITY. *To build technical capacity within a local university, the activity will also procure equipment and supplies deemed essential by the PHL Innovation Lab in order to carry out the mycotoxin analysis.*

Zamorano University is an international university located in Francisco Morazán, Honduras, with a mission to "develop leaders from Latin America and the Caribbean based on academic excellence, Learning by Doing and values and character development, with the goal of contributing to socio-economic progress in the region". Therefore, the establishment of a mycotoxin laboratory at Zamorano University that could support research, surveillance and agricultural development in the country and the region was a prudent decision. With the involvement of faculty, staff and students in the mycotoxin assessment, appropriate training and technical support was provided by PHLIL to the establishment of a Mycotoxin Testing Laboratory as part of the Food Analysis Laboratory at the University of Zamorano.

In the process of establishing the laboratory in Zamorano, equipment, reusables and consumables were purchased either in-country or shipped to Honduras from other

sources. Major equipment (all with a single value of less than US$ 5,000) included those associated with sample storage (i.e. freezer), evaluation (i.e. moisture meters), preparation (i.e. sample dividers, mills), and analysis (i.e. fluorometer and ELISA test readers). Additionally, reusables and consumables necessary to train technicians, share methodology with students, and to evaluate all the samples evaluated in this mycotoxin assessment were provided, as needed. Table 3.3.1 shows a comprehensive list of all materials provided to the laboratory at Zamorano University to be used in this assessment and to allow the lab to be sustainable for future projects. Figure 3.3.1 show a few pictures taken after the mycotoxin testing area had been set up inside of the Food Analysis Laboratory at Zamorano University.

Table 3.3.1 Equipment and materials purchased for the establishment of the mycotoxin analysis laboratory at Zamorano University.

Description	Brand	Quantity
Horizontal Freezers	N/A	3
Semi-Portable Grain Moisture Tester	Dickey John	1
Grain Moisture Tester - Portable	Dickey John	14
Boerner Divider Complete w/2 pans	Seedburo	2
Grain Mill – Romer Series II	Romer	2
Romer Mill – Grinder head assembly	Romer	2
Romer Mill – Grinder cap assembly	Romer	2
Romer Mill – Burr set	Romer	2
Romer Mill – Shear drive assembly	Romer	4
Series-4EX Fluorometer	VICAM	2
AflaTest Fluorometer Instruction Manual	VICAM	1
Stat-Fax 4700 microwell reader	Neogen	2
Digital Scale	Ohaus	2
Balance 6Kg x 0.1g	Ohaus	2
Blender w/Stainless Steel Blender Jar	Waring	2
Eberbach Glass Blender Jar, 500 mL	Eberbach	4
Pipette Aid	Drummond	2
Digital Vortex Mixer	Fisherbrand	2
Pipette 8-channels, 10-100 mL	Finnipipette	3
Pipette 1-channel, 10-100 mL	Finnipipette	4
Pipette 1-channel, 20-200 mL	Finnipipette	4
Pipette 8–channels, 20-200 mL	Finnipipette	3
Pipette 1-channel, 100-1000 mL	Finnipipette	4
pH meter	Oakton	2
12-Position Pump Stand	VICAM	1
Air Pump, 110V	VICAM	6
Bottle Dispenser, 50 mL	Tricontinent	4
Bottle Dispenser, 500 mL	Scilogex	2
Single Position Pump Stand	VICAM	2
Glass Syringe – 10 mL	Clover	REUS*
Plastic Filter Funnels	Fisherbrand	REUS
Plastic Graduated Cylinder, 50 mL	Fisherbrand	REUS

Cuvette Holder – Plastic	ThermoScience	REUS
Wash Plastic Bottle, 500 mL	Fisherbrand	REUS
Glass Graduated Cylinder, 50 mL	VICAM	REUS
Plastic graduate cylinder (100 mL)	Fisherbrand	REUS
Plastic graduate cylinder (1000 mL)	Fisherbrand	REUS
Amber Glass Bottle	VICAM/Fisherbrand	REUS
7 oz. glass jars	VICAM	REUS
Fluorometer Printer Paper	VICAM	CONS**
Pipette tips, 1-200 mL	Fisherbrand	CONS
Pipette tips, 1-200 mL	Corning	CONS
Pipette tips, 1-1000 mL	Corning	CONS
Reagent reservoirs	Pierce	CONS
Plastic beakers	Fisherbrand	CONS
5X Concentrate of 0.1% Tween/2.5% PEG/PBS	VICAM	CONS
Fluted Filter Paper, 24 cm	VICAM	CONS
Microfiber Filter, 1.5 mm, 11 cm	VICAM	CONS
ACS grade Salt	VICAM	CONS
10X Concentrate of PBS, 150 mL	VICAM	CONS
Cardboard lids	Fisherbrand	CONS
Kim wipes tissues	Kimwipes	CONS
Disposable Plastic Beakers	VICAM	CONS
Disposable Glass Cuvettes	Kimblechase	CONS
Disposable Plastic Droppers	VICAM	CONS
Disposable Serological Pipets 10 mL	Fisherbrand	CONS
Disposable Serological Pipets 5 mL	Fisherbrand	CONS
Microfiber Filter Paper, 1.5 mm	VICAM	CONS
Disposable Plastic Cuvettes (CS/250)	Kimberchase	CONS
Mycotoxin Calibration Standards	VICAM	CONS
FumoniTests Immunoaffinity Columns (Pack of 25)	VICAM	CONS
FumoniTest Calibration Standards	VICAM	CONS
FumoniTest Developer A (7.5 mL)	VICAM	CONS
FumoniTest Developer A (15 mL)	VICAM	CONS
FumoniTest Developer B (0.5 mL)	VICAM	CONS
AflaTest Immunoaffinity Columns (Pack of 50)	VICAM	CONS
Aflatest Developer, 50 mL	VICAM	CONS
Aflatest Developer, 25 mL	VICAM	CONS
Aflatoxin in corn, low level, 100 g reference material	ROMER	CONS
Aflatoxin in corn, mid-level, 100g reference material	ROMER	CONS
Fumonisin in corn, mid-level, 100g reference material	ROMER	CONS
Fumonisin in corn, high level, 100g reference material	ROMER	CONS

*REUS – Reusable supplies
*CONS – Consumable supplies

Figure 3.3.1 Images of the mycotoxin testing area inside of the Food Analysis Laboratory at Zamorano University.

Because of the high number of samples that were processed during this assessment, some equipment and materials were purchased in duplicate to help with the flow of analysis. Currently, those duplicate pieces are now available for the potential establishment of a second mycotoxin laboratory in Honduras, independent from Zamorano University or as part of a central surveillance system that could be coordinated by Zamorano University. The duplicate equipment could potentially be made available to researchers at the National University of Honduras (UNAH) where comprehensive training was also offered as part of the capacity building efforts in the area of mycotoxin analysis led by PHLIL in Honduras. More details about the training offered at UNAH are detailed under Task 3.4.

In addition to the training offered in the form of Workshops at Zamorano University and UNAH (detailed under Task 3.4), one researcher from University of Nebraska – Lincoln was placed in Zamorano to further provide technical assistance to the mycotoxin assessment. Dr. Luis Sabillón was in Zamorano from June 11th to July 07th, 2018 to supervise and further train collaborators on sample preparation, mycotoxin analysis and paperwork to be completed for data traceability. During the period that Luis was at Zamorano, adjustments were made to the process for sample preparation, based on the needs of the project, additional students and staff were trained and the whole process was carried out for 200 samples, for both aflatoxin and fumonisin analysis.

Standard Operating Procedures (SOPs) were also provided to the laboratory at Zamorano University to direct sample analysis, data collection and disposal of laboratory waste and excess samples. Detailed procedures were developed, and two sets of laboratory documents were created: "Standard Operating Procedures" and "Data Loggers" for the "Mycotoxin Evaluation in the Corn Value Chain in Western Honduras".

Technicians were also required to pass a proficiency test before they could test samples associated with the mycotoxin assessment in Honduras. After receiving proper training, as part of the proficiency test, technicians were required to run a blind (to them) mycotoxin control sample and report results to the PHLIL researchers. Upon comparison of the results from technicians against the information available for the reference material used for these tests, the technicians were considered either proficient or were required to take additional training. When needed, upon completion of additional training, technicians were required to evaluate another blind sample. Only after they were able to show proficiency for aflatoxin and fumonisin analysis were they allowed to test corn samples that were part of this assessment.

3.4 TRAIN UNIVERSITY LABORATORY STAFF TO CARRY OUT MYCOTOXIN ANALYSIS. The PHL Innovation Lab will work with university professors to train permanent laboratory staff and students to perform the mycotoxin analysis.

One of the major goals of the mycotoxin assessment in Honduras was to build in-country capacity (facilities and personnel) for mycotoxin analysis as a sustainable resource to improve food safety and security in the country. To accomplish this goal workshops and one-on-one training was provided to laboratory technicians from Zamorano University and National University of Honduras (UNAH). The first workshop was carried out at Zamorano University from February 19th until 21st, 2018 and included 13 participants (5 males and 8 females) from UNAH and Zamorano University. The topics covered during this training included: "Mycotoxin Overview and Sampling"; "Sample Preparation and Mycotoxin Analysis", including several types of methods used for mycotoxin testing; and "Sources of Error in Mycotoxin Analysis". Figure 3.4.1 shows a few pictures taken during the training in Zamorano University.

A similar training to the one delivered at Zamorano University was also conducted at the National University of Honduras from August 7th to 9th, 2018. However, in this workshop another module was added: "Mold Isolation and Identification". In this workshop 20 laboratory technicians (7 males and 13 females) were trained and Figure 3.4.2 shows a few images taken during this event.

Figure 3.4.1 Pictures taken during the training for laboratory technicians at Zamorano University (February, 2018).

Figure 3.4.2 Pictures taken during the training for laboratory technicians at National University of Honduras (August, 2018).

Figure 3.4.2 Cont. Pictures taken during the training for laboratory technicians at National University of Honduras (August, 2018).

3.5 DRAFT PROGRESS REPORTS AND FINAL REPORT AND PRESENTATION TO USAID/HONDURAS. *The PHL Innovation Lab will draft monthly progress reports and a final report to be shared with USAID/Honduras, Zamorano University, the Ministry of Agriculture, the Ministry of Health, USAID/Honduras' implementing partners, and other donors.*

Throughout the duration of the mycotoxin assessment in Honduras several trips were made to the country by different members of the PHLIL to evaluate progress, provide capacity building training, and plan different steps of the assessment. For every visit to the country meetings were also planned with the Mission Office in Honduras to update the officers on progress, concerns, and next steps for the assessment. When requested a brief

presentation was made available to the Mission Officers and/or Director with the updates. In other instances, a round table discussion was carried out with the participation of in-country partners like Zamorano University and/or Fintrac. In between trips the Mission Office in Honduras was kept informed of progress, or any delays, by regular informal communication via email and phone calls.

During trips to the country, when possible, meetings with government representatives were also scheduled, in coordination with the Mission. More specifically two meetings with representatives of the Ministry of Agriculture were carried out (September 2017 and February 2018) to communicate the goals and relevance of the mycotoxin assessment, share any results available at the time of the meetings and to seek alliances or collaborations for future capacity building. Table 3.5.1 shows the dates of the trips made by PHLIL members, the main activities accomplished in each trip and the names of those participating on the trips.

Table 3.5.1 Visits to Honduras by PHLIL collaborators, including the main activities accomplished in each trip.

Main Activities Accomplished in Honduras	Dates		PHLIL Collaborators Involved
Visit to meet farmers in the region of the mycotoxin assessment	6/11/2017	6/15/2017	Andréia Bianchini Luis Sabillón
Training of field technicians	11/5/2017	11/11/2017	Andréia Bianchini Luis Sabillón
Training of laboratory technicians in Zamorano University and laboratory setup	2/18/2018	2/22/2018	Andréia Bianchini John Leslie Luis Sabillón
Mycotoxins and mycotoxigenic fungi training at UNAH	8/7/2018	8/9/2018	Andréia Bianchini Dena Bunnel
Mycotoxin dissemination of results workshops	8/5/2019	8/9/2019	Andréia Bianchini Luis Sabillón

3.6 ***WORKSHOP ON PRE- AND POST-HARVEST LOSS REDUCTION.*** *The PHL Innovation Lab will provide administrative and technical support for organizing a workshop to present the results of the mycotoxin assessment and in support of addressing pre- and post-harvest losses. This workshop will be open to representatives from the Government of Honduras, other donors, and USAID/Honduras' implementing partners.*

Awareness about mycotoxins and their association with pre- and post-harvest practices were disseminated in Honduras. Every opportunity to present information and share updates on the mycotoxin assessment in Honduras was taken. Examples of this would include a lecture provided to a group of faculty and staff at UNAH (August 7th, 2018 from 9:00am-12:00pm; 39 participants), a group of students at UNAH (August 7th, 2018 from

2:00-4:00pm; 45 participants), and a group of professionals at the Association of Clinical Chemists and Microbiologists in Honduras (August 7th, 2018).

It is worth mentioning that originally, as part of the plan to complete Task 6, a group of PHLIL collaborators were to travel to Honduras to host a workshop on "Pre- and Post-Harvest Loss Reduction" and to disseminate the results obtained in the "Assessment of Mycotoxin in the Corn Value Chain in Western Honduras". This activity was intended to be open to representatives of the Government in Honduras, other donors and USAID/Honduras' implementing partners. The group scheduled to support this activity included Andreia Bianchini, Jagger Harvey, John Leslie and Luis Sabillón. However due to changes in US Government policies in April 2019 the initial plans could no longer be carried out. With much support from the US Agency for International Development, with special thanks to Dr. Ahmed Kablan, and the support, help and understanding from the Mission Office in Honduras, with special thanks to Anastasia Buyanova, the plans were modified in such a way that smaller, more focused dissemination workshops could be arranged.

The targeted workshops were developed for field technicians associated with Fintrac. In these workshops information about pre- and post-harvest practices and their impact on mycotoxin contamination were disseminated, along with the results obtained in the mycotoxin assessment. Also, these workshops were designed to provide an opportunity for discussion and brainstorming around potential changes and agricultural practices that should be implemented (or discouraged) in the region to address the issues revealed by the mycotoxin survey. A series of questions were used to prompt participants to think about how they could help farmers address the issues associated with mycotoxins in corn going forward.

Table 3.6.1 shows the list of questions used during the focused group. After having an opportunity to exchange information and discuss, a representative of each group was invited to share their thoughts with the rest of the group.

Table 3.6.2 shows the location of each workshop, the number of participants and the date when the training occurred. A total of 92 technicians (88 males and 4 females) participated in these workshops. Figure 3.6.1 show pictures taken during the workshops for dissemination of results of the mycotoxin assessment in the corn value chain in Western Honduras.

Table 3.6.1 Questions used during focused group discussions with field technicians.

Questions
Have you ever discussed about mycotoxins with the farmers? If you do, what have you talked about?
Based on the planting and harvesting time in different departments, do you think any of them are more at risk due to more rain during grain maturation, harvesting and drying time?
Based on the results presented today, do you think there are any agricultural practices that may contribute to exacerbate the risks associated with mycotoxins (examples: length of time farmers leave the corn in the field after maturity or drying practices)? Which practices should be discouraged?
What are the best practices that should be disseminated in Honduras to minimize the risk associated with mycotoxins? Are you aware of any local agricultural practices that could be disseminated as part of these best practices? Which practices should be encouraged? Remember that to be successfully implemented and adopted, practices need to be culturally acceptable.
After learning about best practices associated with post-harvest and the risks associated with molds and mycotoxins, do you intend to teach farmers about molds and mycotoxins? What will you be telling them?

Table 3.6.2 Location, date and number of technicians (male and females) participating in the workshops for results dissemination.

Location and Date	Males	Females	Total
Copán - August 5th, 2019	13	1	14
Lempira - August 6th, 2019	27	0	27
Intibucá - August 6th, 2019	27	0	27
La Paz - August 7th, 2019	21	3	24
(Total numbers)	**88**	**4**	**92**

Figure 3.6.1 Pictures taken during the workshops for dissemination of results of the mycotoxin assessment in the corn value chain in Western Honduras.

Information generated in these focused discussions was essential as it supported the discussions of results and recommendations made under Question 2.6 and were a key part of the "Closing Remarks and Recommendations" section of this report. The dissemination workshops were also important to gather feedback from field technicians related to materials that could be used by them while working with farmers. Based on the discussions, a technical flyer with information for field technicians was created. This is a two-page document that details the findings of the mycotoxin assessment in Honduras and can be distributed to other technicians and stakeholders interested in the information. Additionally, a booklet was produced to be distributed to farmers during visits where technicians discuss the issues associated with mycotoxins and practices that should be implemented or discontinued at farms. Both documents can be found under Appendix 2.

4. CONCLUDING REMARKS AND RECOMMENDATIONS

- A robust sampling design was developed by the PHL Innovation Lab in consultation with the USAID Mission in Honduras, Zamorano University and other in-country collaborators. This design took into consideration all of the departments in the ZOI; as well as Feed the Future Indicators of poverty, and women/children nutritional status. Early phases of the mycotoxin assessment also included the selection of an adequate quantification method, validation of such method and development of Standard Operating Procedures for mycotoxin sampling, as well as sample transportation, preparation and analysis.

- Considering the sampling design and the areas/communities part of the sample collection plan, occurrence of aflatoxin in corn was relatively low. Of the 740 corn samples examined, 146 (20 percent) had detectable levels of aflatoxin, of which 51 (7 percent) surpassed the regulatory limit of 20 µg/Kg established by the U.S. Food and Drug Administration (FDA). It should be noted, however, that this does not confirm that aflatoxin is absent from maize in these areas, since larger sample sizes across multiple seasons and points of the value chain would no doubt uncover some extent of aflatoxin presence. Fumonisin contamination in corn was widespread in the samples collected in areas included by the sampling design within the ZOI. Of the 740 corn samples collected, 719 (~97 percent) had detectable levels of fumonisin, out of which 268 samples (37 percent) had fumonisin levels above the FDA advisory level of 3 mg/Kg for corn destined for direct human consumption.

- Besides aflatoxin and fumonisin, a small-scale study with a subset of 50 corn samples revealed other toxins present in the ZOI. These included nivalenol and zearalenone (*Fusarium* toxins). Moreover, several samples exhibited extremely large concentrations of citrinin and diplodiatoxin, produced by *Penicillium* sp. and *Stenocarpella maydis*, respectively.

- Agricultural practices taking place in selected municipalities of Western Honduras that could help explain the present mycotoxin contamination include: period corn plants remain in field surpassed that needed for plant to reach maturity, drying methods are not effectively appropriate to reduce moisture to adequate levels prior to storage, and traditional storage structures (*e.g.,* tapancos and bags) are still used. For proper crop management and reduced risk of mycotoxin contamination, low cost approaches could include crop rotation, plant debris removal, and watering schedule (*e.g.,* drip irrigation). In the region surveyed, a considerable number of farmers have adopted metallic silos for corn storage. Provided that these storage technology users effectively manage their fields, as well as carry out prompt and effective drying of their crops prior to storage, silos and other emerging low-cost storage alternatives (including hermetic bags) offer promising results against mycotoxin-producing fungi.

- Fumonisin contamination in corn samples was more prominent than aflatoxin, as it was detected in all selected municipalities of the ZOI included in the sample collection plan, with every exposure estimation level exceeding the PMTDI established by JECFA. The exposure assessment, based on the contamination levels observed, showed slightly higher levels for women as they tend to be smaller than men, but with similar daily corn consumption. Therefore, their potential daily exposure is higher.

- At a household level, women play a key role on the choices made for the family, and through education, they may be an agent of change. As they learn and put in place practices such as kernel selection prior to food preparation and diet diversification by the inclusion of other food groups (*e.g.,* meats and vegetables), a lower daily exposure to mycotoxins and increased nutritional status may be achieved in areas such as the ones included in this assessment.

- Training of field technicians, university faculty, staff and students (totaling 441 people) in different aspects of mycotoxins and grains was accomplished by PHLIL in Honduras. Also, the establishment of mycotoxin testing capacity as part of the Food Analysis Laboratory at the University of Zamorano provides the country with the ability to continue research, surveillance and agricultural development in the area of mycotoxins and grain food safety.

- Multiple workshops offered in the ZOI to field technicians to disseminate results from the mycotoxin assessment included awareness about mycotoxins and their association with pre- and post-harvest practices. With the feedback from focused group discussions among PHLIL researchers and field technicians, illustrated materials have been deployed in the ZOI to foster community understanding of mycotoxin threat and how to prevent or decrease their occurrence in food.

5. POTENTIAL FUTURE RESEARCH IN HONDURAS

1. Characterization of the fungal population in the ZOI constitutes a crucial piece of information for plant pathologists/extensionists to understand the taxa involved in corn spoilage and disease. By the use of molecular approaches (e.g. ITS sequencing), fungi identity, as well as population density, can be explored. To our knowledge, no study of this nature has been performed in Honduras. Additionally, with the existing corn samples, a thorough mycological assessment could be performed in order to find non-mycotoxigenic fungal strains of different Aspergilli and Fusaria. This can have tremendous potential as bio-control agents in the ZOI, tailored with organisms from the same location.

2. Mycotoxin contamination in corn can be further evaluated by the use of *in vitro* digestion scenarios, especially after corn has been prepared for consumption using traditional recipes. This will help to better understand the fate of these compounds in the human body. If previously undetected bound mycotoxins (therefore also impervious to diagnostic detection) are released in the gastrointestinal tract, this could mean that the Honduran population is exposed to higher levels of these harmful compounds than those reported by this assessment. Furthermore, a more robust exposure assessment can be obtained by understanding the bio-accessibility potential of each toxin through this type of assay.

3. While not presently regulated, diplodiatoxin and citrinin levels in the subset of corn samples from the ZOI suggest that *Stenocarpella* and *Penicillium* genera are to be taken into consideration for future assessments. Moreover, given the observed co-occurrence of several mycotoxins, exploring any potential synergism (e.g. Fumonisin-Diplodiatoxin) of these harmful compounds on humans and animals can be beneficial. Only by fully understanding the hazards to which a population is exposed, a comprehensive plan to improve health and food safety can be devised.

- END OF DOCUMENT -

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Appendix 1

Mycotoxin Assessment – Survey Document
Producers (Rural Areas): English and Spanish
Markets (Urban Areas): English and Spanish

ASSESSMENT OF MYCOTOXINS IN THE CORN VALUE CHAIN IN WESTERN HONDURAS

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

SURVEY - CORN PRODUCERS

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

I. GENERAL DETAILS OF INTERVIEWEE

Department:

Municipality:

Community:

Name(s) and last name(s) of interviewee

Gender: F _____ M _____

Date of Interview

EXCLUSIVELY FOR FINTRAC'S OFFICE

Sample Identification Number

General Instructions: Listen carefully to the interviewee's answers. For every answer provided, circle the letter(s) of the chosen answer(s) or mark with an "X" in the appropriate box(es). When applicable, write the interviewee's answer.

II. AGRICULTURE AND CORN HARVEST SECTION

1	When did you plant your corn? (Date)	Date: / / Day Month Year	
2	What varieties of corn do you grow?	A. _____ B. _____ C. _____	
3	Is the seed you use for harvesting criolla (native) or improved?	A. Criolla (they choose the best seed) B. Improved (purchased in agroservice)	
4	Do you fold the corn plant in the field?	A. No **(go to question 6)** B. Yes	
5	In what moment do you realize it's time to fold the corn plant?	A. Flower color B. Leaf color C. Nail test D. Mouth test E. Black spot F. Otrer_____	
6	Do you plant your corn together with beans or another crop?	A. No B. Yes Specify the crop: _____ _____	
7	In what moment do you realize it's time for harvesting?	A. Flower color B. Leaf color C. Nail test D. Mouth test E. When the plant is completely dry F. Otros_____	
8	When did you harvest the corn? (Date)	Date: / / Day Month Year	
9	What do you use your harvested corn for?	A. Household consumption B. Sale C. Both D. Don't know/not sure	
10	When and in which moment do you do the cob selection?	A. In the field during the harvesting B. Before drying C. During corn storage	

11	Do you dry the corn before storing it?	A. No **(go to question 14)**	
		B. Yes	
12	How or in which way do you dry the corn?	**1. In the corn field, before cutting the cob (dobla)**	
		2. In the cob, after being cut	
		A. Putting the cobs on the roof	
		B. Putting the cobs on nylon and exposing them to the sun	
		C. Inside the house	
		D. Using a dryer	
		E. Other way (specify):_____	
		3. After shelling the cob	
		A. On nylon, sun-dried	
		B. Inside the house or cellar	
		C. Using a dryer	
		D. Other way (specify): _____	
13	At what point do you know that the corn is well dried and suitable for storage?	A. Nail test	
		B. Mouth test	
		C. Field test (sound)	
		D. Other: _____	
III. HANDLING AND STORAGE CONDITIONS SECTION			
14	Do you store the corn shelled or in cobs?	A. In cobs	
		B. Shelled **(go to question 17)**	
15	If you store the corn in cobs, where and how is it stored?	A. Traditional corn crib (Troja)	
		B. Improved corn crib (Troja mejorada)	
		C. Lodge (tapanco)	
		D. Sacks	
		E. Mancuerna	
16	If you store the corn in cobs, how long is it stored?	A. 1 Month	
		B. 2 Months	
		C. 3 Months	
		D. 4 or more months	
17	If you shell the cobs, how do you do it?	A. By hand	
		B. Using a sheller (machine)	
		C. Other (specify): _____	
18	After shelling, do you clean your corn?	A. No **(go to question 20)**	
		B. Yes	
19	How or in what way do you clean the shelled corn?	A. By hand (separating bad grains and garbage one by one)	
		B. Throwing it from side to side to let the air clean it (letting it "air out")	
		C. Washing it	
		D. Sifting it	
		E. Do not clean	
		F. Don't know/not sure	

ASSESSMENT OF MYCOTOXINS IN THE CORN VALUE CHAIN IN WESTERN HONDURAS

SURVEY - CORN PRODUCERS

20	How the shelled corn is stored?	A. Sacks B. Silo C. Barrel D. Drawer E. Other_____	
21	If you store it in a silo, do you use pills to treat the corn (phosphin treatment)?	A. Yes B. No C. Do not use silo D. Don't know/not sure	
22	How long do you keep/store the produced corn?	A. 1 Month B. 2 Months C. 3 Months D. 4 or more months	
23	During the time that you store the corn, do you check both grain and storage quality? (moisture, leakage, pests, etc...)	A. Yes B. No **(go to question 25)** C. Don't know/not sure	
24	How often do you check your corn during the time that it is stored?	A. Once a week B. Once every 15 days C. Once a month D. Once every 2 months E. Don't know/don't answer	
25	Do you have Pest Control (insects, mice, fungus), during the storage period of corn?	A. Yes B. No **(go to question 27)** C. Don't know/not sure	
26	At what point do you do Pest Control?	A. _____ B._____ C. _____	
27	What are the main reasons of corn losses, from harvest to the final consumption?	A. _____ B._____ C. _____ D. _____	
28	What is done with the corn that has poor quality (broken, with pests)?	A. You give it to animals B. You throw it away C. You consume it D. Don't know/not sure	
29	How many people live in the household?		
30	How many individuals under five (5) live in the household?		

31	How much corn is needed on a daily basis to support your household?	A. Less than 2 lb	
		B. 2 to 3 lb	
		C. 3 to 4 lb	
		D. 4 to 5 lb	
		E. More than 5 lb	
32	How much corn is needed on a monthly basis to support your household?	A. Less than 5 lb	
		B. 10 lb	
		C. 10 to 20 lb	
		D. 20 to 30 lb	
		E. 30 to 40 lb	
		F. More than 40 lb	

DOUBLE-CHECK THAT ALL ANSWERS APPLICABLE TO EACH CASE HAVE BEEN ANSWERED BY THE INTERVIEWEE

THANK THE INTERVIEWEE FOR THE TIME DEDICATED TO THIS STUDY

IV. ADMINISTRATIVE SECTION

Interviewer's name	
Review signature of field supervisor	
Date of Review	

EVALUACIÓN DE MICOTOXINAS EN LA CADENA DE VALOR DEL MAÍZ EN EL OCCIDENTE DE HONDURAS

FEED THE FUTURE "The U.S. Government's Global Hunger & Food Security Initiative"

ENCUESTA - PRODUCTOR

FEED THE FUTURE "The U.S. Government's Global Hunger & Food Security Initiative"

I. DATOS GENERALES DEL ENTREVISTADO

Departamento: _____

Municipio: _____

Comunidad: _____

Nombres y Apellidos del Entrevistado(a): _____ Sexo: F _____ M _____

Fecha de Entrevista: _____

PARA USO EXCLUSIVO DE OFICINA FINTRAC

Número de Identificación de la Muestra

Instrucciones Generales: Escuche atentamente las respuestas del entrevistado. Por cada pregunta, encierre con un circulo la opción u opciones de respuesta(s) apropiada(s) y marcar con una "X" la casilla correspondiente. Cuando aplique, escribir la respuesta del entrevistado.

II. SECCION AGRICULTURA Y CULTIVO DE MAIZ

1	¿Cuándo sembró usted el maíz? (Fecha)	Fecha: / / Día Mes Año	
2	¿Qué tipo de variedad de maíz cultiva usted?	A. _____ B. _____ C. _____	
3	¿La semilla que utiliza para su cultivo es criolla o mejorada?	A. Criolla (escogen la mejor semilla) B. Mejorada (comprada en agropecuarias)	
4	¿Dobla usted la planta de maíz en el campo?	A. No **(pase a la pregunta 6)** B. Si	
5	¿Basado en que hace usted la dobla de la planta de maíz?	A. Por el color de la flor B. Por el color de las hojas C. Por muestreo de uña D. Por muestreo bucal E. Por punto negro F. Otros:_____	
6	¿Siembra usted el maíz junto con frijol u otro cultivo?	A. No B. Si Especifique el cultivo: _____ _____	
7	¿En qué momento hace la tapisca o cosecha?	A. Color de la flor B. Color de las hojas C. Por muestreo de uña D. Por muestreo bucal E. Cuando la planta está totalmente seca F. Otros:_____	
8	¿Cuándo cosechó usted el maíz? (Fecha)	Fecha: / / Día Mes Año	
9	¿Para qué utiliza su cosecha?	A. Para consumo en el hogar B. Para comercialización o venta C. Ambos D. No sabe/no responde	
10	¿Cuándo y en qué momento realiza la selección de mazorcas?	A. En el campo durante la cosecha (milpa) B. Antes de secarlo C. Cuando se está almacenando el maíz	

11	¿Secan el maíz antes de guardarlo?	A. No **(pase a la pregunta 14)**	
		B. Si	
12	¿Cómo o de que forma secan usted el maíz?	**1. En la milpa, antes de cortar la mazorca (dobla)**	
		2. En la mazorca, después de haber sido cortada	
		A. Colocan las mazorcas sobre el techo	
		B. Colocan las mazorcas en nylon y las ponen al sol	
		C. Dentro de la casa	
		D. Utilizan una maquina de secado	
		E. Otra forma:_____	
		3. Después de desgranado	
		A. En nylon secado al sol	
		B. Dentro de la casa o alguna galera	
		C. Utilizan alguna maquina de secado	
		D. Otra forma: _____	
13	¿Cómo se prueba el maíz para verificar si está seco para guardarlo o almacenarlo?	A. Por prueba de uña	
		B. Por prueba bucal	
		C. Por prueba de campo (sonido)	
		D. Otros: _____	
III. SECCION DE MANEJO Y CONDICIONES DE ALMACENAMIENTO			
14	¿Guarda su maíz en grano o en mazorca?	A. En mazorca	
		B. Desgranado **(pase a la pregunta 17)**	
15	¿Si lo guardan en mazorca, dónde o cómo lo guardan?	A. Troja tradicional	
		B. Troja mejorada	
		C. Tapanco	
		D. Costales	
		E. Mancuerna	
16	¿Si lo guardan en mazorca, por cuanto tiempo lo guardan?	A. Un mes	
		B. Dos meses	
		C. Tres meses	
		D. Cuatro meses o mas	
17	¿Si desgranan las mazorcas, cómo las desgranan?	A. Manualmente	
		B. Utiliza una desgranadora (maquina)	
		C. Otro (especifique): _____	
18	¿Después de desgranado, limpia usted el maíz?	A. No (**pase a la pregunta 20**)	
		B. Si	
19	¿Cómo o de qué manera limpian el maíz en grano?	A. Manualmente (escogiendo uno por uno los granos malos y dañados)	
		B. Lanzándolo de un lado al otro para que el aire lo limpie (dejando que se "airee")	
		C. Lavándolo	
		D. Cernido	
		E. No lo limpia	
		F. No sabe/no responde	

EVALUACIÓN DE MICOTOXINAS EN LA CADENA DE VALOR DEL MAÍZ EN EL OCCIDENTE DE HONDURAS

FEED THE FUTURE "The U.S. Government's Global Hunger & Food Security Initiative"

ENCUESTA - PRODUCTOR

FEED THE FUTURE "The U.S. Government's Global Hunger & Food Security Initiative"

20	¿Cómo guardan el maíz desgranado?	A. Costales	
		B. Silo	
		C. Tonel	
		D. Cajón	
		E. Otros_____	
21	¿Si lo guardan en silo, utilizan pastillas para curar el maíz?	A. Si	
		B. No	
		C. No usa silo	
		D. No sabe/no responde	
22	¿Por cuánto tiempo guardan el maíz producido?	A. Un mes	
		B. Dos meses	
		C. Tres meses	
		D. Cuatro meses o mas	
23	¿Durante el tiempo que guarda el maíz, revisa usted la calidad del grano y del lugar de almacenaje? (humedad, picado, ratones, goteras, insectos, etc.)	A. Si	
		B. No **(pase a la pregunta 25)**	
		C. No sabe/no responde	
24	¿Con qué frecuencia revisa su maíz durante el tiempo de almacenamiento?	A. Una vez por semana	
		B. Una vez cada 15 días	
		C. Una vez por mes	
		D. Una vez cada dos meses	
		E. No sabe/no responde	
25	¿Hace un control de plagas (insectos, ratones, hongos) durante el periodo de almacenamiento de maíz?	A. Si	
		B. No **(pase a la pregunta 27)**	
		C. No sabe/no responde	
26	¿En que momento hace usted control de plagas?	A. _____	
		B._____	
		C. _____	
27	¿Cuáles son las principales razones de las pérdidas de maíz, desde la cosecha hasta el consumo final?	A. _____	
		B._____	
		C. _____	
		D. _____	
28	¿Qué se hace con el maíz que tiene mala calidad (roto, con plagas)?	A. Se lo dan a los animales	
		B. Lo tiran o lo desechan	
		C. Lo consumen en la casa	
		D. No sabe / no responde	
29	¿Cuántas personas viven en el hogar?		
30	¿Cuántas personas menores de cinco (5) años viven en el hogar?		

31	¿Cuánto maíz se necesita diariamente para mantener su hogar?	A. Menos de 2 libras	
		B. De 2 a 3 libras	
		C. De 3 a 4 libras	
		D. De 4 a 5 libras	
		E. Más de 5 libras	
32	¿Cuánto maíz se necesita mensualmente para mantener su hogar?	A. Menos de 5 libras	
		B. 10 libras	
		C. De 10 a 20 libras	
		D. De 20 a 30 libras	
		E. De 30 a 40 libras	
		F. Más de 40 libras	

REVISE QUE TODAS LAS PREGUNTAS QUE APLIQUEN, HAYAN SIDO CONTESTADAS POR EL ENTREVISTADO

DE LAS GRACIAS AL ENTREVISTADO POR EL TIEMPO CEDIDO PARA ESTE ESTUDIO

IV. SECCION ADMINISTRATIVA

Nombre del Entrevistador(a)	
Firma de Revisión del Supervisor de Campo	
Fecha de Revisión	

ASSESSMENT OF MYCOTOXINS IN THE CORN VALUE CHAIN IN WESTERN HONDURAS

SURVEY - CORN SELLERS

I. GENERAL DETAILS OF INTERVIEWEE

Department: _____

Municipality: _____

Community: _____

Name(s) and last name(s) of interviewee _____ Gender: F _____ M _____

Date of Interview _____

EXCLUSIVELY FOR FINTRAC'S OFFICE

Sample Identification Number

General Instructions: Listen carefully to the interviewee's answers. For every answer provided, circle the letter(s) of the chosen answer(s) or mark with an "X" in the appropriate box(es). When applicable, write the interviewee's answer.

II. PURCHASE AND QUALITY SECTION

1	What varieties of corn do you sell?	A. _____ B._____ C. _____ D._____	
2	Where does the corn you sell come from (where was it grown, harvested)? Where do you buy it?	Origin: _____ _____ Purchase: _____ _____	
3	What quality parameters you use when buying the corn you sell?	A. _____ B._____ C. _____ D. _____ E._____	
4	Do you check the moisture of the corn before buying it? If you check it, what is the percentage of moisture that is considered safe to buy corn?	A. No B. Yes Moisture Percentage: _____ %	
5	How do you test corn to verify if it is dry or has a safe moisture content?	A. Nail test B. Mouth test C. By testing the moisture content D. Other (specify): _____	

III. HANDLING AND STORAGE CONDITIONS SECTION

6	After bying, do you clean your corn?	A. No **(go to question 8)** B. Yes	
7	How or in what way do you clean the corn?	A. By hand B. By machine C. Sifting it D. Do not clean E. Other, specify: _____ F. Don't know/not sure	
8	How do you store the purchased corn?	A. Sacks B. Silo C. Barrel E. Other (specify): _____	

9	If you store it in a silo, do you use pills to treat the corn (phosphin treatment)?	A. Yes B. No C. Do not use silo D. Don't know/not sure	
10	How long does the corn stay stored before it is sold?	A. 1 Month B. 2 Months C. 3 Months D. 4 or more months E. Other (specify): _____	
11	Do you check the quality of the grain and the storage location during the time that the corn is stored before selling it? (humidity, mice, leaks, insects, etc.)	A. No (**go to question 13**) B. Yes C. Don't know/not sure	
12	How often do you check your corn during the time that it is stored?	A. Once a week B. Once every 15 days C. Once a month D. Once every 2 months E. Other (specify): _____ F. Don't know/don't answer	
13	Do you have Pest Control (insects, mice, fungus), during the storage period of corn?	A. Yes B. No C. Don't know/not sure	
14	At what point do you do Pest Control?	A. _____ B._____ C. _____	
15	If you detect that corn has dropped its quality during storage, what do you do with that low quality corn?	A. Sells it as animal feed B. Sells it at a lower price for human consumption C. Throw it away D. Don't know/not sure	

DOUBLE-CHECK THAT ALL ANSWERS APPLICABLE TO EACH CASE HAVE BEEN ANSWERED BY THE INTERVIEWEE

THANK THE INTERVIEWEE FOR THE TIME DEDICATED TO THIS STUDY

IV. ADMINISTRATIVE SECTION

Interviewer's name

Review signature of field supervisor

Date of Review

EVALUACIÓN DE MICOTOXINAS EN LA CADENA DE VALOR DEL MAÍZ EN EL OCCIDENTE DE HONDURAS

ENCUESTA - VENDEDOR

I. DATOS GENERALES DEL ENTREVISTADO

Departamento: _____

Municipio: _____

Comunidad: _____

Nombres y Apellidos del Entrevistado(a): _____ Sexo: F _____ M _____

Fecha de Entrevista: _____

PARA USO EXCLUSIVO DE OFICINA FINTRAC

Número de Identificación de la Muestra

Instrucciones Generales: Escuche atentamente las respuestas del entrevistado. Por cada pregunta, encierre con un circulo la opción u opciones de respuesta(s) apropiada(s) y marcar con una "X" la casilla correspondiente. Cuando aplique, escribir la respuesta del entrevistado.

II. SECCION DE COMPRA Y CALIDAD

1	¿Qué variedades de maíz vende usted?	A. _____ B._____ C. _____ D._____	
2	¿De dónde proviene el maíz que vende (dónde fue cultivado, cosechado)? ¿Dónde lo compra?	Procedencia:_____ _____ Compra: _____ _____	
3	¿Qué parámetros de calidad usas para comprar el maíz que vendes?	A. _____ B._____ C. _____ D. _____ E._____	
4	¿Revisa usted la humedad del maíz antes de comprarlo? Si la revisa, ¿Cuál es el porcentaje de humedad que se considera seguro para comprar el maíz?	A. No B. Si Porcentaje de humedad: _____ %	
5	¿Cómo se prueba el maíz para verificar si está seco o si tiene un contenido de humedad seguro?	A. Por prueba de uña B. Por prueba bucal C. Por prueba de contenido de humedad D. Otro, especifique: _____	

III. SECCION DE MANEJO Y CONDICIONES DE ALMACENAMIENTO

6	¿Después de comprado, limpia usted el maíz?	A. No (**pase a la pregunta 8**) B. Si	
7	¿Cómo o de qué manera limpia el maíz?	A. Manualmente B. Maquina C. Cernido D. No lo limpia E. Otros, especifique: _____ F. No sabe/no responde	

8	¿Cómo guardan/almacenan el maíz que compra?	A. Costales B. Silo C. Tonel E. Otro, especifique: _____	
9	¿Si lo guardan en silo, utilizan pastillas para curar el maíz?	A. No B. Si C. No usa silo D. No sabe/no responde	
10	¿Por cuánto tiempo permanece almacenado el maíz antes de su venta?	A. Un mes B. Dos meses C. Tres meses D. Cuatro meses E. Otro, especificque: _____	
11	¿Durante el tiempo que el maíz pasa almacenado antes de venderlo, revisa usted la calidad del grano y del lugar de almacenaje? (humedad, picado, ratones, goteras, insectos, etc.)	A. No (**pase a la pregunta 13**) B. Si C. No sabe/no responde	
12	¿Con qué frecuencia revisa el maíz durante el tiempo de almacenamiento?	A. Una vez por semana B. Una vez cada 15 días C. Una vez por mes D. Una vez cada dos meses E. Otro, especifique: _____ F. No sabe/no responde	
13	¿Hace un control de plagas (insectos, ratones, hongos), durante el periodo de almacenamiento de maíz?	A. Si B. No C. No sabe/no responde	
14	¿En que momento hace usted control de plagas?	A. _____ B._____ C. _____	
15	Si usted detecta que el maíz a bajado su calidad durante el almacenamiento, ¿Qué hace con ese maíz de baja calidad?	A. Lo vende como alimento animal B. Lo vende a menor precio para consumo humano C. Lo tira o lo desecha D. No sabe / no responde	

REVISE QUE TODAS LAS PREGUNTAS QUE APLIQUEN, HAYAN SIDO CONTESTADAS POR EL ENTREVISTADO

DE LAS GRACIAS AL ENTREVISTADO POR EL TIEMPO CEDIDO PARA ESTE ESTUDIO

IV. SECCION ADMINISTRATIVA

Nombre del Entrevistador(a)	
Firma de Revisión del Supervisor de Campo	
Fecha de Revisión	

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Appendix 2

Materials for Dissemination in Honduras

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Assessment of Mycotoxins in the Corn Value Chain in Western Honduras

Findings of the evaluation carried out by the Feed the Future Innovation Laboratory for the Reduction of Postharvest Loss. *October 2019*

Corn is a staple in the diet of most Hondurans. It is consumed several times a day, mainly in the form of tortillas. However, this grain is prone to contamination by compounds produced by molds called *mycotoxins* that can have toxic effects on humans and animals. Unfortunately, data on the presence of mycotoxins in the Honduran corn value chain is almost non-existent. In response to this knowledge gap, corn samples (n=975) were randomly collected in markets and directly from farmers in the months of January to July 2018.

Six departments of western Honduras were included in the study: Copán, Intibucá, Lempira, La Paz, Ocotepeque and Santa Bárbara (Fig. 1). These departments are located in the dry corridor, an area characterized by low rainfall and variable weather conditions.

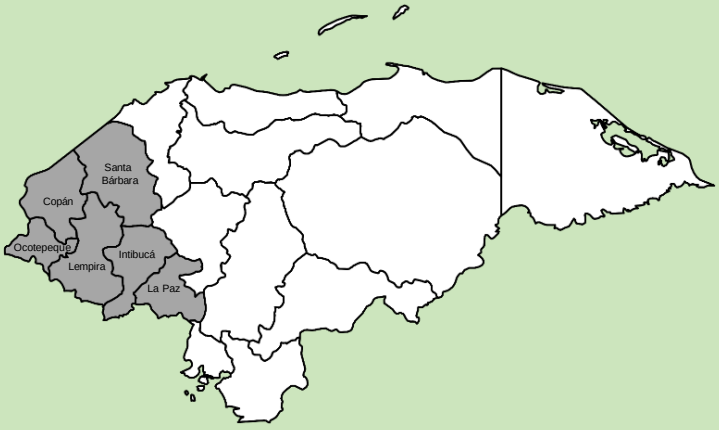
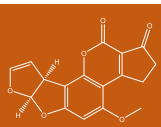


Fig 1. Western region of Honduras where the mycotoxin study was carried out.



Aflatoxins

Family of toxins found in agricultural crops such as corn. They are potent carcinogens and can affect human and animal organs, particularly the liver and kidneys.

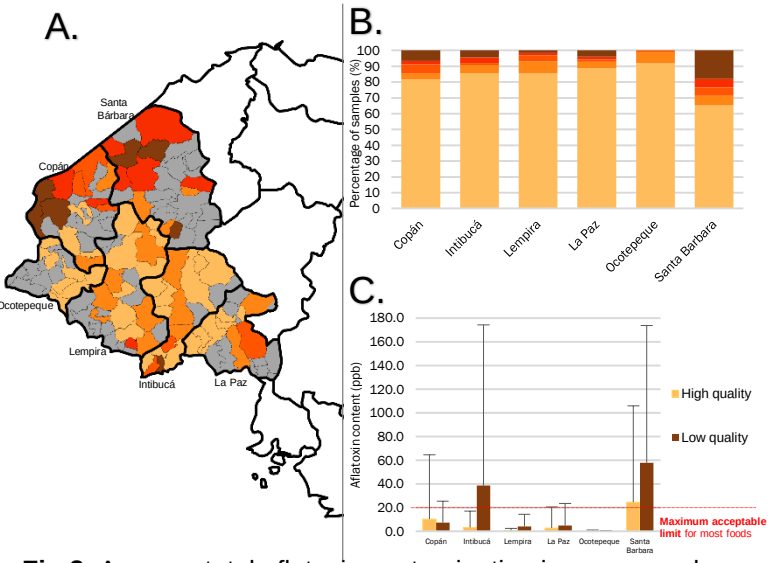


Fig 2. Average total aflatoxin contamination in corn samples:

A. Wester region of Honduras. Non-analyzed municipalities are shown in gray (■). Range of contamination <0.25 parts per billion [ppb] (■), ≥1 – 4 ppb (■), >4 – 10 ppb (■), >10 – 20 ppb (■), >20 ppb (■).
B. Proportions of samples contaminated with mycotoxin per department.
C. Mycotoxin contamination in corn of high (consumption) and low (discard) quality.

Figure 2 shows the average contamination by total aflatoxins in corn samples by municipality. The magnitude of the contamination is indicated by the color code. Of the samples analyzed for aflatoxins (n=975), the department of Santa Barbara presented the highest number of positive samples (35%), of which 38 samples were at levels above 20 parts per billion (ppb), maximum acceptable limit for most foods. In general, aflatoxins were less frequent than fumonisins in the region of study, as several samples were below the detection limit (1 ppb) for aflatoxins. Based on the levels of contamination, the department of Ocotepeque showed the lowest levels of aflatoxin contamination among the 6 departments evaluated, with 92% of the samples collected in this area showing levels below the detection limit of the method used.

An invisible threat. It can be seen in Figure 2C that, on average, both visibly affected (low quality) corn and good quality corn contained detectable levels of mycotoxins. Low quality corn samples showed aflatoxin levels between 1.6 and 490 ppb (data not shown), indicating the importance of a grain selection after harvest, and prior to storage or consumption.

Fumonisins are mycotoxins that prevail in corn, sorghum and other agricultural products. These toxins have been linked to cancer of the esophagus and spina bifida in humans, as well as various diseases in animals.

Fumonisins

Figure 3 shows the average contamination of corn samples with total fumonisins by municipality. The magnitude of the contamination is indicated by the color code. Of the samples analyzed for fumonisin (n=972), the department of Santa Barbara presented the highest number of positive samples (99%), of which 78 samples were at levels above 3 parts per million (ppm), maximum recommended limit for most foods. Regardless of the source of the corn, cultivated by farmers or acquired in the market, departments showed various average levels of contamination with this toxin. In general, this toxin is prevalent in the study region, with only 3.2% of samples showing contamination below the detection limit (0.25 ppm).

Samples of low quality corn showed levels of fumonisins between 9 and 31 ppm (data not shown), and visibly good quality corn presented levels between 13 and 41 ppm, confirming the ubiquitous presence of *Fusarium*, the mold that produces this compound, in this area. Due to the fumonisin levels reported in this study, it is recommended that corn should be harvested in a timely manner and dried to safe levels (<14% moisture) before storage. A grain selection is also important, separating and discarding all that is visibly damaged.

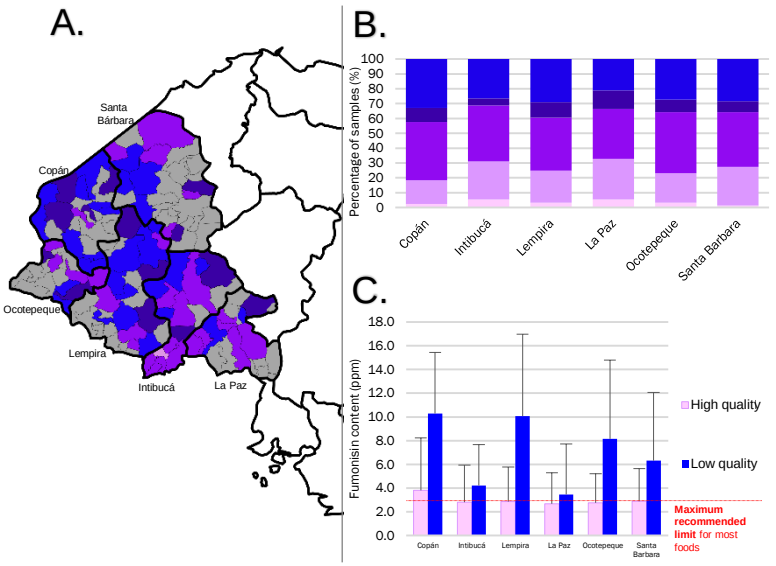


Fig 3. Average total fumonisin contamination in corn samples:
A. Wester region of Honduras. Non-analyzed municipalities are shown in gray (■). Range of contamination <0.25 parts per million [ppm] (■), >0.25 – 1 ppm (■), >1 – 3 ppm (■), >3 – 4 ppm (■), >4 ppm (■).
B. Proportions of samples contaminated with mycotoxin per department.
C. Mycotoxin contamination in corn of high (consumption) and low (discard) quality.

Recommendations to maintain the quality and safety of grains

- Corn should be harvested in a timely manner after the bending of corn stalks. Excessive time in the field after grain maturity can lead to mold growth and mycotoxin production.
- During drying, spread the grains to form a thin layer that ensures greater surface contact with the environment. The grain pile must be mixed during drying to prevent the internal part from retaining mositure.
- The use of dryers is recommended whenever possible, to ensure uniform and effective drying of corn.
- It is important that the grain to be used as animal feed is also of good quality. Through visual inspection, separate the grains that show disease or damage, and discard them.
- If animals consume low quality grain, this may result in decreased production of animal products, like milk, meat, or eggs.
- Remember **DICE**: **Dry** the corn before storing it. **Inspect** the storage before placing the grain. **Clean** the storage and surroundings regularly. **Eat** varied, well-balanced, meals.

Summary of Main Findings

- ✓ Grain selection is recommended during harvest, during shelling, before storage and before preparing corn for human consumption.
- ✓ Fumonisins appear to be the most frequent group of toxins in the region of study. However, several samples were positive for aflatoxins, a carcinogenic compound.
- ✓ Both producers and consumers in the corn value chain must manage this grain following good practices to maintain its quality and not compromise its safety.

This material is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the Feed the Future initiative. The contents are the responsibility of the Innovation Lab for the Reduction of Post-Harvest Loss (PHLIL) and do not necessarily reflect the views of USAID or the United States government.

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Evaluación de Micotoxinas
en la Cadena de Valor de Maíz en el Occidente de Honduras

Hallazgos de la evaluación realizada por el Laboratorio de Innovación *Feed the Future* para la Reducción de Pérdidas Poscosecha. *Octubre 2019*

El maíz es un alimento básico en la dieta de la mayoría de los hondureños. Se consume varias veces al día, principalmente en forma de tortillas. Sin embargo, este grano es propenso a la contaminación por compuestos producidos por mohos llamados *micotoxinas* que pueden tener efectos tóxicos en humanos y animales. Desafortunadamente, los datos sobre la presencia de micotoxinas en la cadena de valor del maíz de Honduras son casi inexistentes. En respuesta a esta brecha de conocimiento, muestras de maíz (n=975) fueron recolectadas aleatoriamente en mercados y directamente con agricultores en los meses de Enero a Julio del 2018. Seis departamentos del occidente de Honduras fueron incluidos en el estudio: Copán, Intibucá, Lempira, La Paz, Ocotepeque y Santa Bárbara (Fig. 1). Estos departamentos se ubican en el corredor seco, un área caracterizada por poca lluvia y condiciones climáticas muy variables.

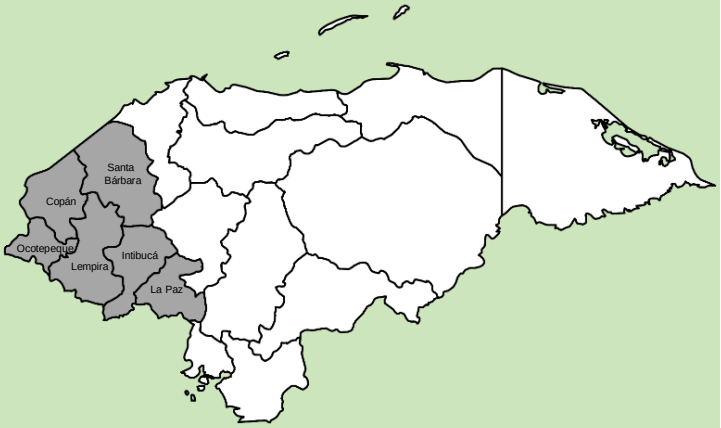
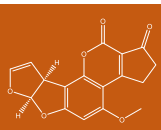


Fig 1. Región occidental de Honduras donde se llevó a cabo el estudio de micotoxinas.



Aflatoxinas

Familia de toxinas que se encuentran en cultivos agrícolas como el maíz. Son carcinógenos potentes y pueden afectar a todos los órganos, particularmente el hígado y los riñones.

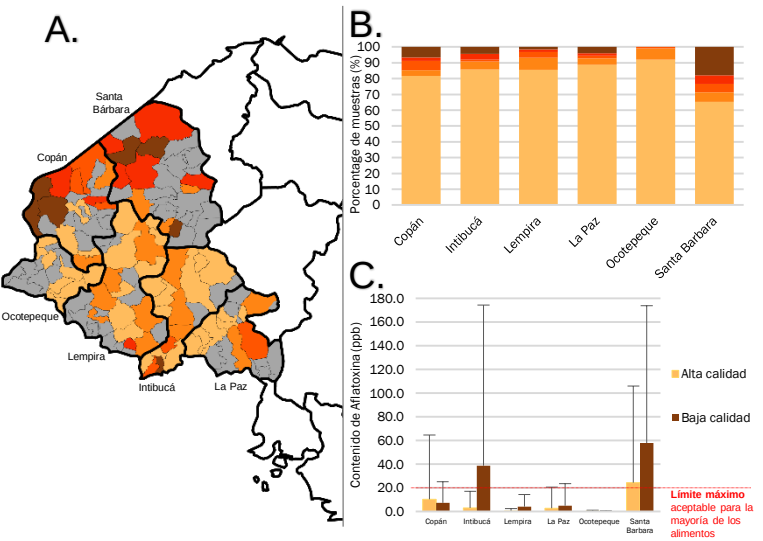


Fig 2. Contaminación promedio de aflatoxinas totales en maíz:

A. Región occidental de Honduras. Municipios no analizados mostrados en gris (■). Rangos de contaminación <1 partes por millón [ppb] (■), ≥1 – 4 ppb (■), >4 – 10 ppb (■), >10 – 20 ppb (■), >20 ppb (■).
B. Proporción de niveles de contaminación departamental.
C. Contaminación en maíz de alta (consumo) y baja (descarte) calidad.

La figura 2 muestra el promedio de la contaminación por aflatoxinas totales en las muestras por municipio. La magnitud de la contaminación se indica por el código de color. De las muestras analizadas para aflatoxinas (n=975), el departamento de Santa Bárbara presentó el mayor numero de muestras positivas (35%), de las cuales 38 muestras se encontraban con niveles superiores a las 20 partes por billón (ppb), límite máximo aceptable para la mayoría de los alimentos. En general, las aflatoxinas fueran menos frecuentes que las fumonisinas en la región de estudio, ya que varias muestras estaban por debajo del límite de detección (1 ppb) para aflatoxinas. En base a los niveles de contaminación, el departamento de Ocotepeque mostró los menores niveles de contaminación por aflatoxinas entre los 6 departamentos evaluados, con 92% de las muestras recolectadas en esta región estando por debajo del límite de detección del método.

Una amenaza invisible. Se aprecia en la Figura 2C que en promedio, tanto el maíz visiblemente afectado (descarte) como el maíz de buena calidad contenían niveles detectables de micotoxinas. Las muestras de descarte mostraron niveles de aflatoxinas entre 1.6 y 490 ppb (datos no mostrados), indicando la importancia de una clasificación del grano luego de la cosecha, y previo a su almacenaje o consumo.

Las fumonisinas son micotoxinas que prevalecen en el maíz, sorgo y otros productos agrícolas. Estas toxinas se han relacionado con el cáncer de esófago y espina bífida en el ser humano y con varias enfermedades en animales.

Fumonisinas

La figura 3 muestra el promedio de contaminación de fumonisinas totales. La magnitud de la contaminación se indica por el código de color. De las muestras analizadas para fumonisina (n=972), el departamento de Santa Bárbara presentó el mayor numero de muestras positivas (99%), de las cuales 78 muestras se encontraban con niveles superiores a las 3 partes por millón (ppm), límite máximo sugerido para la mayoría de los alimentos. Indiferentemente de la fuente del maíz, cultivado o adquirido en el mercado todos los departamentos mostraron distintos niveles de contaminación con fumonisina. En general, esta toxina es prevalente en la región de estudio, con únicamente 3.2% de muestras por debajo del límite de detección (0.25 ppm).

Muestras de maíz de baja calidad mostraron niveles de fumonisinas entre 9 y 31 ppm (datos no mostrados), y maíz de catalogado como buena calidad presentó niveles entre 13 y 41 ppm, confirmando la presencia ubicua de Fusarium, el moho que produce este compuesto. Debido a los niveles de fumonisina reportados en la región de estudio, es recomendable que el grano sea cosechado de forma oportuna y secado a niveles seguros (<14% humedad). Es también importante una clasificación del grano, separando y desechando todo aquello visiblemente dañado.

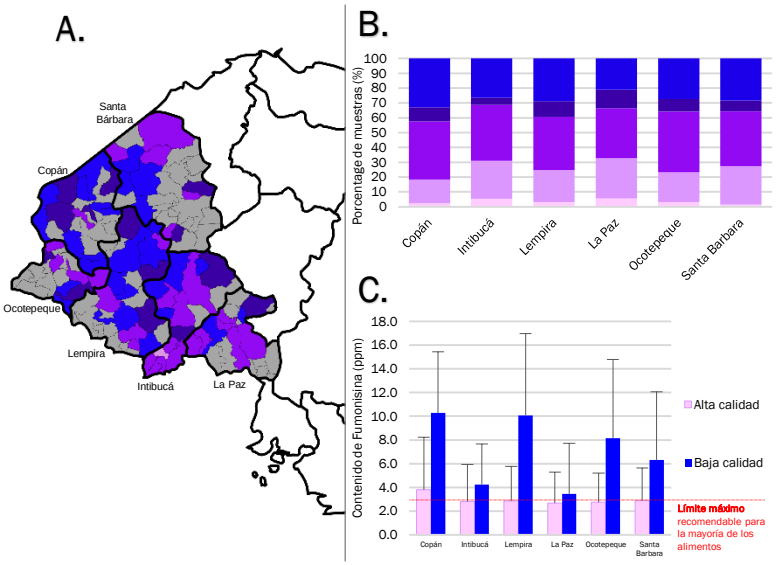


Fig 3. Contaminación promedio de fumonisinas totales en maíz:

A. Región occidental de Honduras. Municipios no analizados mostrados en gris (■). Rangos de contaminación <0.25 partes por millón [ppm] (■), >0.25 – 1 ppm (■), >1 – 3 ppm (■), >3 – 4 ppm (■), >4 ppm (■).
B. Proporción de niveles de contaminación departamental.
C. Contaminación en maíz de alta (consumo) y baja (descarte) calidad.

Recomendaciones para mantener la calidad e inocuidad de granos

- El maíz debe ser cosechado de forma oportuna después de la dobla. Un tiempo excesivo en el campo después de la madurez del grano puede llevar al crecimiento de mohos y la producción de micotoxinas.
- Durante el secado, distribuya los granos para formar una capa delgada que asegure un mayor contacto del grano con el ambiente. Se debe mover la pila de granos para evitar que la parte interna se quede húmeda.
- Es recomendable el uso de secadores siempre que sea posible, para garantizar el secado uniforme y eficaz del maíz.
- Es importante que el grano que se vaya a dar a los animales como alimento sea también de buena calidad. Mediante una inspección visual, separe los granos que se vean con enfermedad o con agujeros y descártelos.
- Si los animales llegan a consumir el grano de menor calidad, esto puede resultar en una disminución del rendimiento de producción de leche o carne, o huevos.
- Recuerde SILO: **Secar** el maíz antes de almacenarlo. **Inspeccionar** el almacenaje antes de colocar el grano. **Limpiar** el almacenaje y alrededores, regularmente. **Observar** el grano durante el almacenamiento.

Resumen de Hallazgos Principales

- ✓ La selección de granos es recomendable durante la cosecha, durante el desgrane, antes del almacenamiento y antes de preparar el maíz para el consumo humano.
- ✓ Las fumonisinas parecen ser el grupo de toxinas más frecuente en la región de estudio. Sin embargo, varias muestras fueron positivas para aflatoxinas, un compuesto cancerígeno.
- ✓ Tanto productores como intermediarios en la cadena de valor del maíz deben manipularlo siguiendo buenas prácticas para mantener su calidad y no comprometer la inocuidad del mismo.

Este material es posible gracias al generoso apoyo del pueblo estadounidense a través de la Agencia de los Estados Unidos para el Desarrollo Internacional (USAID) bajo la iniciativa Feed the Future. Los contenidos son responsabilidad del Laboratorio de Innovación de Reducción de Pérdidas Poscosecha y no reflejan necesariamente los puntos de vista de USAID o del gobierno de los Estados Unidos.

This guide is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the Feed the Future initiative. The contents are the responsibility of the Innovation Lab for the Reduction of Post-Harvest Loss (PHLIL) and do not necessarily reflect the views of USAID or the United States government.

FEED THE FUTURE

USAID
FROM THE AMERICAN PEOPLE

Post-Harvest Loss Reduction
FEED THE FUTURE INNOVATION LAB

KANSAS STATE UNIVERSITY

University of Nebraska Lincoln

Fintrac

FEED THE FUTURE

USAID
FROM THE AMERICAN PEOPLE

Post-Harvest Loss Reduction
FEED THE FUTURE INNOVATION LAB

KANSAS STATE UNIVERSITY

University of Nebraska Lincoln

Fintrac

Agriculture Guide

Training guide focused on smallholder agriculture in western Honduras


In Summary

To avoid health problems related to mycotoxins:

- ✓ **Check** the corn quality in field.
- ✓ Perform a corn **selection** prior to drying.
- ✓ **Dry** corn to adequate levels to avoid lossed due to mold and pests.
- ✓ Use **appropriate storage methods** to store your corn.
- ✓ Perform a corn selection **prior** to cooking.

Also...

- ✓ **Hygiene** in food preparation reduces the risk of illness for your family.
- ✓ The **sale of corn surplus** generates income that can help diversify your diet.

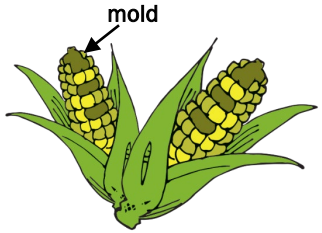
Preface

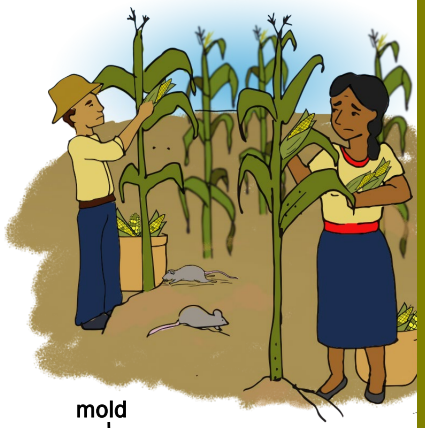
Corn has a cultural and historical significance in Honduras. Additionally, it is considered the staple crop of the Honduran population, particularly for families in the rural area of the country. In effect, this basic grain that occupies the largest planting and harvesting area in the country.

As you will see in this guide, there are many practices that are recommended to maintain the quality of corn after harvest, and maintain the health of consumers.

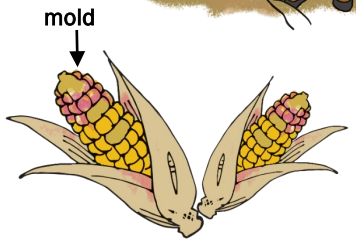
Corn Harvest

Corn should not be harvested early. A corn harvested before maturity reduces crop yield and is more difficult to dry before storage.



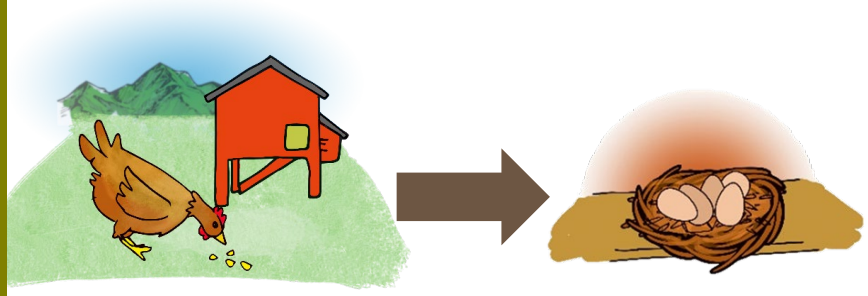


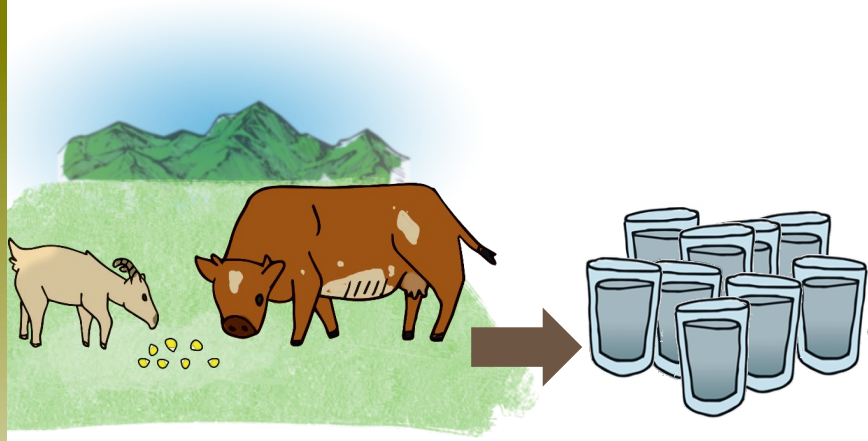
The bending of corn helps with the drying of the plant, but after done, you should not leave the corn for an extended period in the field to reduce the risk of grain exposure to molds, birds and rain.



Many molds can produce toxins that cause disease. Examples include those that grow in grains, nuts and fruits. The toxins produced by these molds are known as mycotoxins.

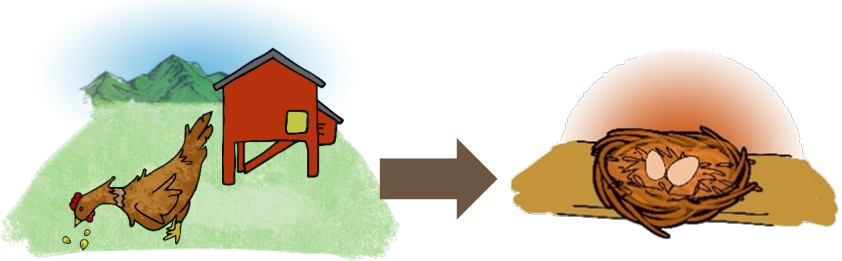
Animal Welfare

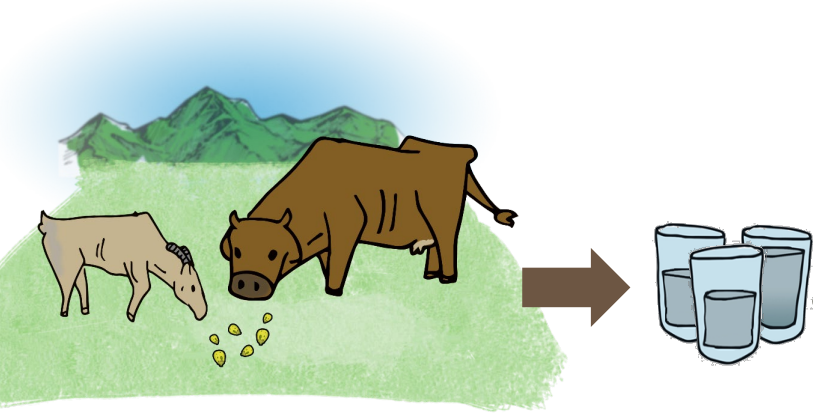




Animals fed with good quality corn remain healthy, and have a better yield, producing enough food for your family.

Animal Welfare



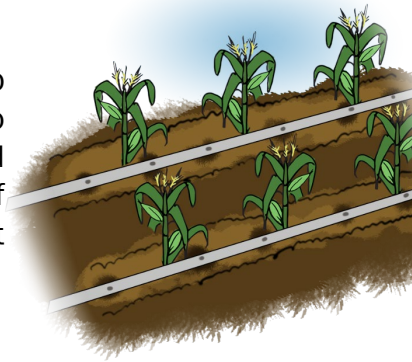


Animals fed with corn of poor quality, possibly contaminated with mycotoxins, have a lower productive and reproductive yield, producing less food for your family.

In addition, mycotoxins may reach fresh milk when a cow/goat has consumed contaminated food.

Corn Harvest

If possible, use a drip irrigation system or similar to improve crop growth and yield, make efficient use of water, and reduce nutrient leaching loss.



The optimum time of harvest depends on the corn variety. In general, it is expected that the plants have completed their cycle, which coincides with the appearance of a black dot on the base of each kernel.

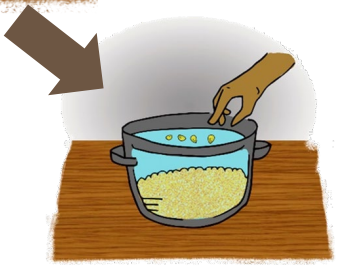
The bending of corn is recommended for a faster drying in the field, and decreasing bird damage. It also facilitates shelling and drying for later storage. The bending should be done when the husks are white and the black dot of the grain is visible. Depending on the region, corn may remain bent from 30 to 45 days; consult with field technicians in the area.

Drying Practices

During drying, if corn is placed directly on the ground or near animals, it can get contaminated with bacteria and molds. In addition, if corn is not sufficiently dried, molds that produce toxins can grow during storage.

The consumption of spoiled corn puts your family's health at risk. Mycotoxin poisoning can be aggravated if the person who ingests contaminated food is already ill or malnourished.

Consumption Practices



At the household level, a selection of the grain before its consumption, along with a varied well-balanced diet, reduces the risk of disease for your family.

Consumption Practices

Inadequate hygiene practices during food preparation can put your family's health at risk.

In addition, a diet consisting mostly of corn and corn-derived products increases the chances of exposure to mycotoxins.

Drying Practices

In the field, a timely bending of corn, followed by an appropriate selection of harvested and dried grain, reduces the risk of disease for your family.

After harvest, an important practice is to separate the good corn from the one that is damaged or moldy.

If possible, use methods that dry corn in a faster fashion, such as using solar dryers.

Storage Practices

During storage, if the storage space is not clean and organized, and if the storage structures (silo, drums) are not in good condition, the corn may be exposed to pests and deterioration.

A corn that was not properly selected or dried, and that is not stored properly, can not only be exposed to pests, but can also be harmful to your family as it may be contaminated with mycotoxins.

Storage Practices

It is important to perform grain quality checks. Take into account humidity, temperature, the level of insect infestation, molds, foreign matter, and rodents and birds droppings.

A corn that was previously selected and dried after harvest and properly stored, reduces the risk of disease for your family.

Esta guía es posible gracias al generoso apoyo del pueblo estadounidense a través de la Agencia de los Estados Unidos para el Desarrollo Internacional (USAID) bajo la iniciativa *Feed the Future*. Los contenidos son responsabilidad del Laboratorio de Innovación de Reducción de Pérdidas Poscosecha y no reflejan necesariamente los puntos de vista de USAID o del gobierno de los Estados Unidos.

FEED THE FUTURE
Iniciativa mundial del Gobierno de los EE.UU. contra el hambre y la inseguridad alimentaria

USAID
DEL PUEBLO DE LOS ESTADOS UNIDOS DE AMÉRICA

FEED THE FUTURE LABORATORIO DE INNOVACIÓN
Reducción de Pérdidas en Poscosecha

KANSAS STATE UNIVERSITY

University of Nebraska Lincoln

Fintrac

FEED THE FUTURE
Iniciativa mundial del Gobierno de los EE.UU. contra el hambre y la inseguridad alimentaria

USAID
DEL PUEBLO DE LOS ESTADOS UNIDOS DE AMÉRICA

FEED THE FUTURE LABORATORIO DE INNOVACIÓN
Reducción de Pérdidas en Poscosecha

KANSAS STATE UNIVERSITY

University of Nebraska Lincoln

Fintrac

Guía de Agricultura

Guía de entrenamiento enfocado a agricultura minifundista en el occidente de Honduras

En Resumen

Para evitar problemas de salud relacionados a micotoxinas:

- ✓ **Verifique** la calidad del maíz en el campo.
- ✓ Realice una **selección** antes del secado.
- ✓ **Seque** adecuadamente el maíz para evitar pérdidas por mohos y plagas.
- ✓ Utilice **métodos adecuados** para almacenar correctamente su maíz
- ✓ Seleccione el maíz **antes** de cocinarlo.

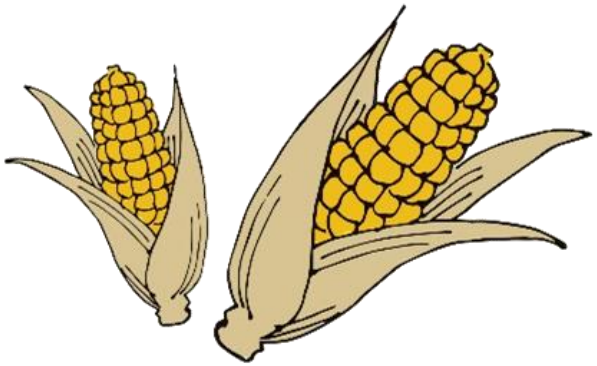
Además...

- ✓ La **higiene** en la preparación de alimentos reduce el riesgo de enfermedades para su familia.
- ✓ La **venta del excedente** de maíz genera ingresos que pueden ayudar a diversificar su dieta.

Prefacio

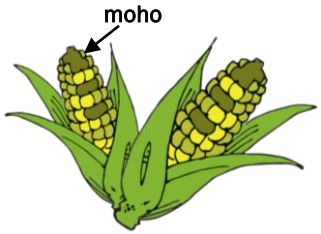
El maíz tiene un significado cultural e histórico en Honduras. Además, es considerado la base de la alimentación de la población hondureña, principalmente para familias en el área rural del país. En efecto, es el grano básico que ocupa la mayor superficie de siembra y cosecha en el país.

Como verá en esta guía, existen muchas prácticas que son recomendables para mantener la calidad del maíz después de la cosecha, y mantener la salud de los consumidores.

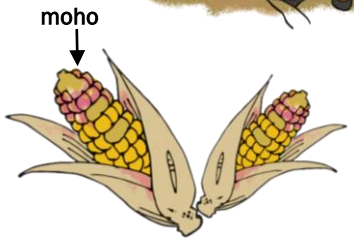


Cosecha de Maíz

No se debe cosechar el maíz antes de tiempo. Un maíz cosechado antes de su madurez, reduce el rendimiento de la cosecha y es más difícil de secar antes del almacenamiento.

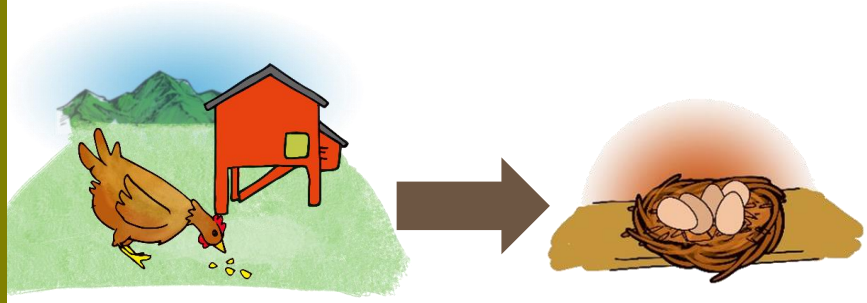


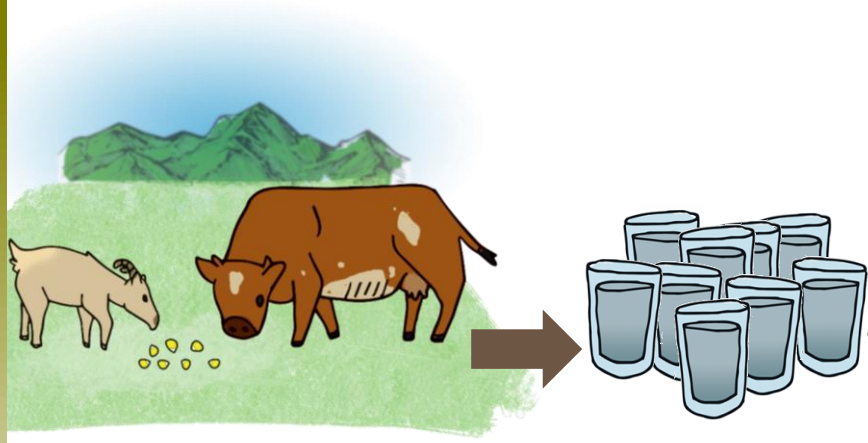
La dobla ayuda con el secado del maíz, pero después de la dobla, no se debe dejar el maíz mucho tiempo en el campo para que el grano no esté muy expuesto a mohos, aves y lluvia.



Muchos mohos pueden producir toxinas que causan enfermedades. Ejemplos incluyen los que crecen en granos, nueces y frutas. Las toxinas producidas por estos mohos se conocen como micotoxinas.

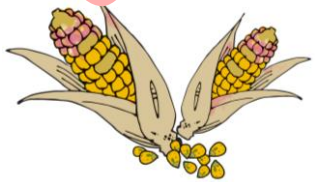
Bienestar Animal

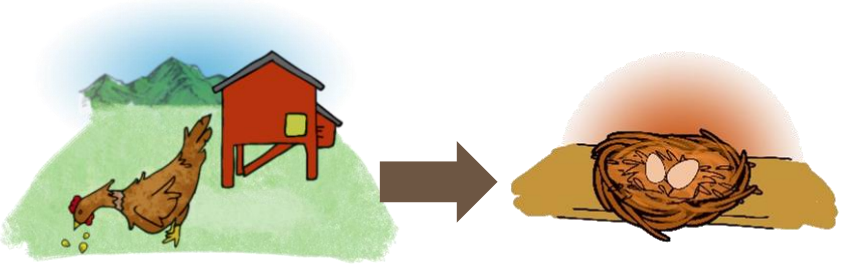


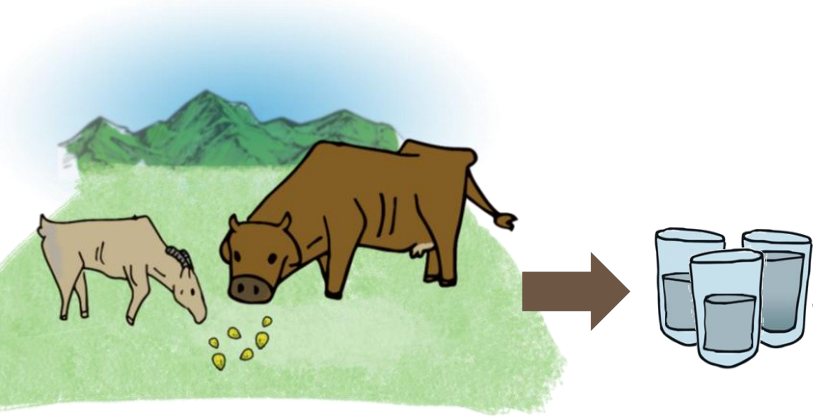


Animales alimentados con maíz de buena calidad se mantienen saludables, y tienen un mejor rendimiento, produciendo suficiente alimento para su familia.

Bienestar Animal



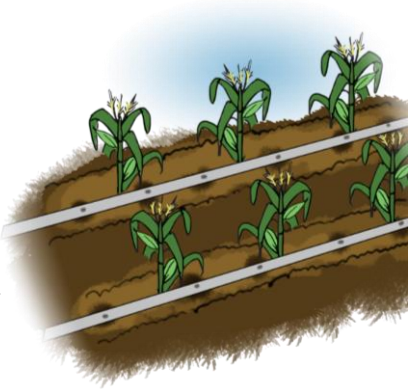




Animales alimentados con maíz de mala calidad, posiblemente contaminado con micotoxinas, tienen un menor rendimiento productivo y reproductivo, produciendo menos alimento para su familia.

Además, es posible que las micotoxinas lleguen a la leche fresca cuando una vaca/cabra ha consumido alimento contaminado.

Cosecha de Maíz



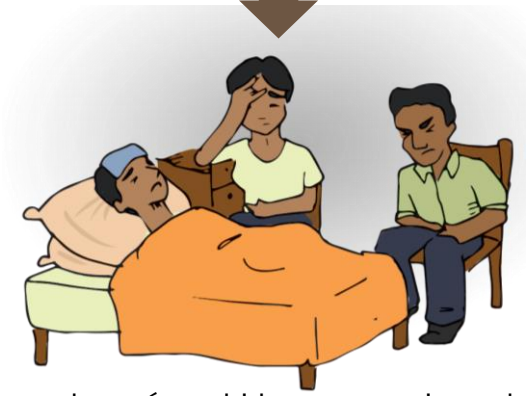
De ser posible, utilice un sistema de riego por goteo o similar para mejorar el crecimiento y el rendimiento del cultivo, haciendo uso eficiente del agua, y reduciendo pérdida de nutrientes.

El momento óptimo de la cosecha depende del tipo de maíz. En general, se espera a que las matas hayan completado su ciclo, lo cual coincide con la aparición del punto negro del grano.

La dobla del maíz es recomendada para un secado más rápido en el campo, y disminuir el daño causado por pájaros. También facilita el desgranado y el secado para el almacenamiento. La dobla se debe realizar cuando la tusa esté blanca y se vea el punto negro del grano. Dependiendo de la región, el maíz puede permanecer doblado entre 30 y 45 días; consulte con técnicos de campo del área.

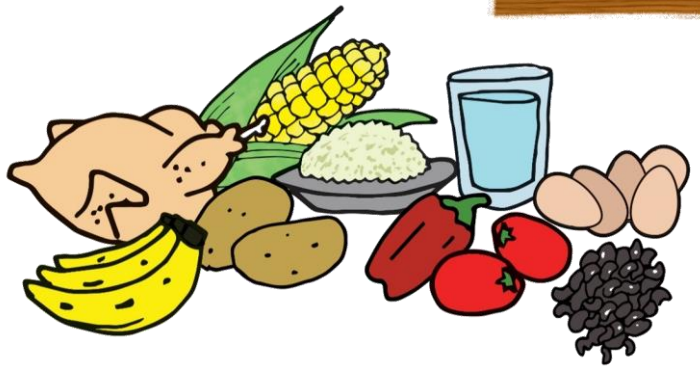
Prácticas de Secado

Durante el secado, si se coloca el maíz directamente sobre la tierra o cerca de animales, puede contaminarlo con bacterias y mohos. Además, si el secado no es apropiado, durante el almacenamiento pueden crecer mohos que producen toxinas.



El consumo de maíz podrido pone en riesgo la salud de su familia. La intoxicación por micotoxinas puede agravarse si la persona que ingiere los alimentos contaminados ya está enferma o desnutrida.

Prácticas de Consumo



En el hogar, una selección del grano antes de su consumo, y una dieta variada, reduce el riesgo de enfermedades para su familia.

Prácticas de Consumo

Prácticas de higiene inadecuadas durante la preparación de los alimentos puede poner en riesgo la salud de su familia.

Además, una dieta con un alto contenido de maíz incrementa las probabilidades de exposición a micotoxinas.

Prácticas de Secado

En el campo, una dobla oportuna, seguido de una selección del grano cosechado y secado apropiado, reduce el riesgo de enfermedades para su familia.

Luego de la cosecha, una práctica importante es separar el maíz bueno de aquel que se vea dañado o con moho.

De ser posible, utilice métodos que sequen el maíz rápidamente como el uso de secadores solares.

Prácticas de Almacenamiento

Durante el almacenamiento, si el espacio de almacenaje no está limpio y organizado, y además, si las estructuras de almacenamiento (silo, toneles) no están en buen estado, el maíz puede estar expuesto a plagas y deterioro.

Un maíz que no fue seleccionado o secado apropiadamente, y que no es almacenado correctamente, puede no sólo estar expuesto a plagas, sino que también puede ser dañino para su familia ya que puede estar contaminado con micotoxinas.

Prácticas de Almacenamiento

Es importante realizar inspecciones de la calidad del grano. Tomar en cuenta la humedad, la temperatura, el nivel de infestación de insectos, los mohos, las materias extrañas, y la contaminación causada por roedores y pájaros.

Un maíz que fue previamente seleccionado y secado luego de la cosecha y correctamente almacenando, reduce el riesgo de enfermedad para su familia.