CIMMYT
International Maize and Wheat Improvement Center

Postharvest problems and practices in rural Mexico

Summary of diagnostic surveys with smallholder farmers

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Introduction

In Mexico, the estimated 2.8 million farmers who produce maize (*Zea mays*) do so under a great diversity of environmental and economic situations (Eakin et al., 2014). Many of these farmers are considered smallholders, who operate on less than 20 hectares, and in rural areas without adequate access to land tenure, capital, credit, and other inputs that may contribute to adequate maize yields (Eakin et al., 2015). Under such production constraints, these smallholder farmers may not produce enough maize to satisfy their consumption needs in the home (which may include feeding livestock), or to sell in order to recuperate some of the costs of production (Appendini and Quijada, 2016; Hellin et al., 2009). Additionally, maize is subject to losses due to poor handling and pests throughout the production system. After harvest and during storage, postharvest losses have been estimated as high as 25% in parts of Mexico (Arahon Hernandez and Carballo Carballo, 2014; García-Lara and Bergvinson, 2007). Such losses not only limit the quantity of food available for home use, but can also result in quality losses, reducing opportunities for farmers to sell their grain when prices are high, or even rendering the grain unsafe for human consumption (Affognon et al., 2015; Jones and Alexander, 2014). Adequate postharvest practices—all practices conducted during and after harvest, including drying and storing—can help prevent these losses, while also helping farmers maintain the desired quality of their grain for its end use.

Losses can occur at any point during the postharvest process. Harvesting when the grain is too moist may result in inadequate water content later, and moist grain provides an excellent environment for the development of various fungi (Doohan et al., 2003). Drying the grain in the field, where the farmer has little opportunity to monitor the grain and little control over climatic factors, may result in insect infestations as well (Tigar et al., 1994). Many farmers store grain for upwards of 6 to 12 months, using traditional wooden structures (*trojes*), which are essentially small outdoor rooms, or in polypropylene sacks which may be exposed to the environment and inadequately protect the grain (Manuel Rosas et al., 2007). Additionally, some farmers may choose to treat their grain with pesticides to protect it, and little is known about how widespread this practice is, what chemicals the farmers may be using (e.g., if these chemicals are actually approved for use in stored grain for human consumption) and how they apply the chemical (e.g., whether they are using protective equipment during application) (Ognakossan et al., 2013). All of these losses result in wasted time and resources on the part of the farmer, and threaten food security for many of Mexico's rural poor (Stathers et al., 2013).

Alternatives exist throughout the postharvest system for minimizing losses, for example the use of hermetic technologies like metallic silos or specially designed plastic bags for storage can help reduce losses in quantity and quality of stored grain (García-Lara et al., 2013; Manuel Rosas et al., 2007). The adoption of these technologies is dependent on a variety of factors, including the perceived benefit of their use and their initial cost, both of which are dependent on local conditions, e.g., where losses associated with traditional storage methods are high and the cost of transporting a metallic silo, for example, to the location of its use is low, adoption may be higher (Jones and Alexander, 2014; Tefera et al., 2011). However, understanding such local conditions is necessary prior to the recommendation of alternatives for mitigating postharvest losses.

The decisions that farmers make regarding their postharvest practices and their methods for storage are extremely diverse, depending on tradition, knowledge of alternatives, the local environmental conditions, and availability of technologies. Because of this diversity in approaches to postharvest management and grain storage, few summaries and case studies exist on a regional level in Mexico regarding how farmers decide to harvest, asses grain moisture and decide on the appropriate time to store their products. Additionally, we have an understanding of the pests that may cause damage, but little information exists regarding which pests farmers perceive to cause the most damage in the grains in specific states and regions within Mexico (García-Lara and Bergvinson, 2007). By assessing the perspectives of smallholder farmers on such aspects of their postharvest system, CIMMYT and our collaborators can help prioritize interventions for minimizing losses in different areas. To obtain these perspectives, CIMMYT's collaborators conducted a survey of rural smallholder farmers between 2013 and 2016, with a focus on smallholder farmers because of the opportunities for effective interventions for reducing postharvest losses amongst this group (Gitonga et al., 2013). The responses the farmers provide, while largely qualitative and subjective, can provide valuable baseline information for understanding their current postharvest practices, as well as a summary of important pests and areas for future research.

Materials and methods

Study sites and participant selection

As part of the Sustainable Intensification Program (SIP), the International Maize and Wheat Improvement Center (CIMMYT) works through collaborators (e.g., universities, research institutions, farmers' groups, farm advisors, etc.) to conduct research on various themes related to the production of maize and other grains, with the end goals of increasing yields, augmenting farmer incomes, and conserving natural resources, among others. Since 2013, CIMMYT began work in the postharvest system, which includes investigating the behavior in different environments of various practices for grain storage, training farmers and other stakeholders in appropriate grain storage practices, and outreach and extension of recommendations for minimizing losses after harvest. As part of this work, our collaborators conducted interviews with smallholder farmers in the Mexican states of Chiapas, Chihuahua, Mexico City, Mexico State, Guerrero, Hidalgo, Jalisco, Michoacán, Morelos, Nayarit, Oaxaca, Puebla, Quintana Roo, Tlaxcala, Veracruz, and Yucatán (Fig. 1). The states where the interviews were conducted were dependent on where CIMMYT conducts postharvest activities, with our level of activity in a state being a function of regional need and capacity in each area. The farmers interviewed were selected by the collaborators conducting the interviews, and were generally those that assisted a postharvest training or demonstration event organized by the collaborators. Because CIMMYT's postharvest work focuses specifically on smallholder farmers, the results presented here are not representative of farmers of all scales in a certain state, but rather for the smallholders producing maize in those states.

Data collection

The survey covers over one hundred questions related to the agronomic and postharvest practices of grain farmers, including basic data regarding the age of the farmer interviewed, family size, size of their operation (total hectares planted), and average maize yields. The survey includes questions regarding the farmer's practices for harvesting, drying, and conserving or storing their grain, and common problems and pests they experience during each step of their postharvest activities. Many of the questions were open, so the farmers could provide an appropriate description of their activities for their production system, for example "What steps do you take at the moment of harvest, or how do you determine the appropriate time to harvest?"

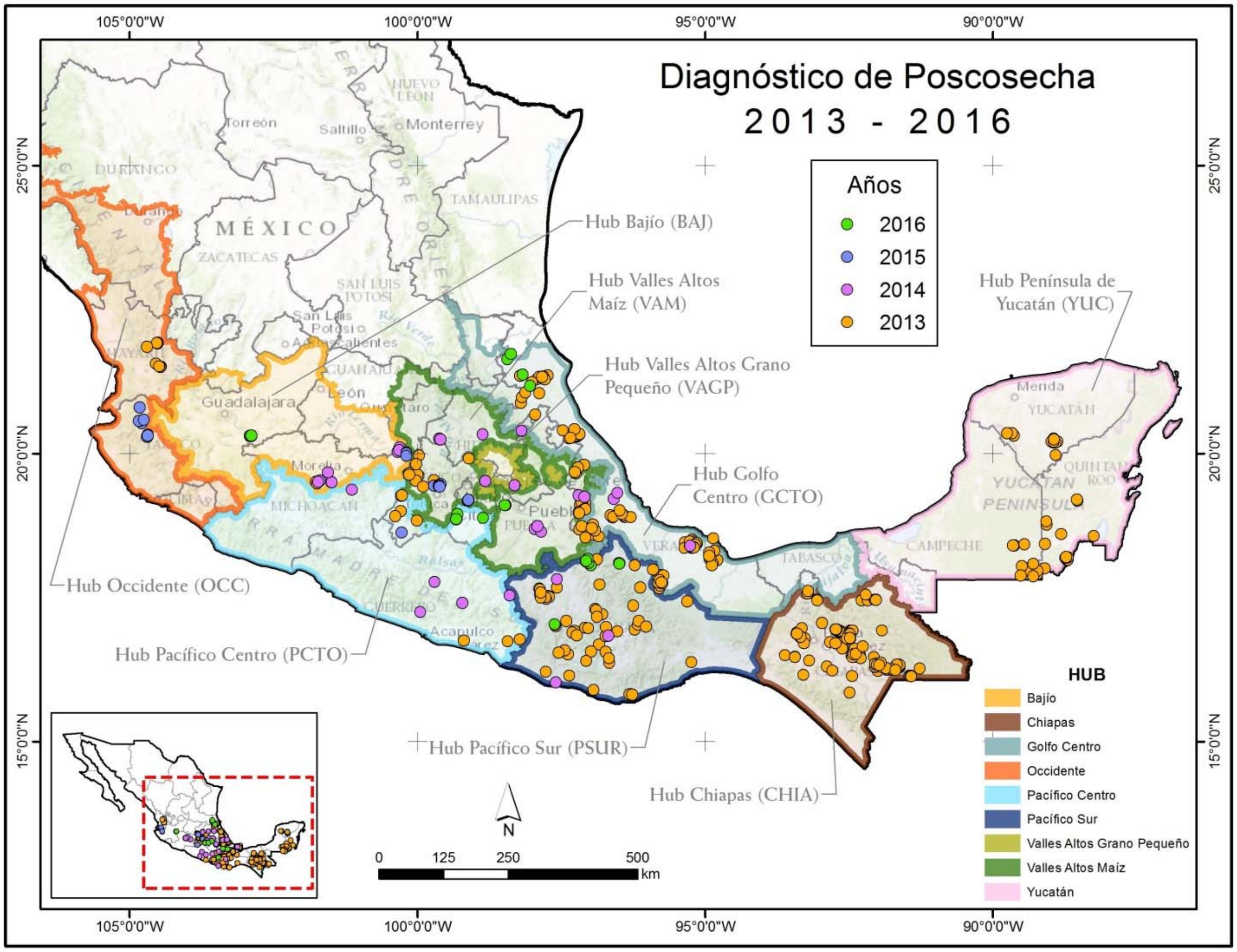

Fig. 1. Map of the locations where farmers were surveyed in each state and hub. Hubs represent agroecologically distinct areas. One data point represents one survey, although coordinates were not provided for all surveys (n = 719).

In three states, we have less than 10 interviews—Chihuahua (1), Hidalgo (5), and Tlaxcala (1)—these are not included in the final summary, as the sample size is too small to be representative. Not all of the farmers provided answers for all of the questions in the survey, and in these cases, we only report the total number of producers who responded to the question and the associated number of percentages (i.e., the percentages of the farmers who actually responded). We did not exclude any surveys, although the questions farmers chose to answer varied. Many of the farmers also produce more than one grain, but all of the data we provide for yield, steps at the time of harvesting, storage practices, etc. refer only to maize, as it is the primary crop most of these producers consume and store. The numeric data, for example, yields, percentages of losses, etc. are estimations provided by the farmers; however, these numbers provide important information regarding their perspectives. If a farmer provided a numeric range, we provide the average of that range. We did not attempt to interpret the answers provided by the farmers if their answers were not clear. For example, in the question regarding end use, some farmers would indicate that they used 50% of grain in their home, but would not indicate the use for the other 50%; we did not automatically assume that it would have been sold.

Results

Participants

The collaborators completed a total of 1,299 interviews in 13 Mexican states (Table 1). The average age of the farmers in all states is over 40, with average family sizes of greater than 4. In most states, more than 75% of farmers report agriculture as their primary economic activity, with lower percentages only found in Mexico State (53.8%), Mexico City (60.0%) and Quintana Roo (61.4%).

Table 1. Number of interviews conducted in each state, average age and family size reported by the farmers (± standard deviation), and percent of farmers in each state reporting agriculture as their primary economic activity.

State	Total Number of Interviews	Age			Family Size			Agriculture as Primary Economic Activity	
		n[a]	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*	*n*	*%*
Chiapas	272	264	45.5	(13.06)	272	5.5	(2.20)	270	92.6%
Guerrero	10	8	46.9	(10.30)	10	4.1	(1.29)	9	100.0%
Jalisco	25	24	56.9	(13.77)	24	7.1	(3.22)	24	91.7%
Mexico City	15	15	49.6	(16.10)	15	4.1	(1.53)	15	60.0%
Mexico State	39	36	53.8	(11.86)	39	5.4	(2.63)	39	53.8%
Michoacán	104	101	56.4	(13.52)	103	4.5	(2.04)	103	78.6%
Morelos	32	32	55.2	(11.54)	32	5.0	(2.53)	32	90.6%
Nayarit	12	12	50.9	(12.22)	11	5.5	(1.51)	12	100.0%
Oaxaca	360	358	48.1	(14.70)	356	4.5	(1.90)	359	87.7%
Puebla	39	38	48.3	(10.82)	35	5.1	(1.33)	38	84.2%
Quintana Roo	45	45	46.7	(11.17)	45	5.2	(1.78)	44	61.4%
Veracruz	331	331	52.6	(12.46)	328	4.5	(1.58)	325	90.5%
Yucatan	15	15	46.8	(10.34)	15	6.2	(2.68)	15	93.3%
Total	*1299*	1,279	*49.9*	*(13.66)*	1,285	*4.9*	*(2.04)*	1,285	*86.8%*

[a] n = total number of farmers responding to each question

Production system

The average of the total land operated by the farmers was highly variable depending on the state, with an average low of 1.42 hectares (ha) in Nayarit and an average high of 4.42 ha in Puebla, with high variability in Puebla (Table 2). The size of these operations, and the water regime in which the farmers produce their maize (rainfed, irrigation, or with both systems), further indicate that the survey is representative of smallholder farmers in each state. In total, 94% of the farmers surveyed produced in rainfed conditions, only 2% use irrigation, and 3% rely on both sources of water. Mexico State has the highest percentage of irrigation use, with 32%. The state reporting the lowest average yield per hectare, Yucatán, also reports the highest average number of family members. Access to more land was not directly linked with higher yields, however, as the highest and lowest average yields reported by the farmers were both in states with moderate access to land (Michoacán and Yucatan, respectively). Likewise, a higher percentage of farmers reporting use of hybrid seed instead of a native variety did not correspond with higher average yields, for example, in Mexico City, 23 (of 25 farmers) responded to the question regarding their choice of seed, and 61% reported using hybrid seed, with only moderate average yields.

Table 2. Percent of farmers producing in rainfed conditions, with irrigation, or with both water regimes, average (± standard deviation) hectares operated, average (± standard deviation) estimated yield (t ha^{-1}) as reported by the farmers, and percent of farmers in each state reporting each type of seed planted

	Land Operated (ha)			% of Farmers Producing under Different Conditions				Yield (t ha^{-1})			% of Farmers Using Each Type of Seed			
State	*n*	*Avg.*	*(±sd)*	*n*	*Rainfed*	*Irrigation*	*Mixed*	*n*	*Avg.*	*(±sd)*	*n*	*Native*	*Hybrid*	*Both*
Chiapas	271	1.89	(1.63)	269	100%	0%	0%	228	1.79	(1.38)	269	95%	5%	0%
Guerrero	8	1.84	(0.35)	9	89%	0%	11%	7	2.27	(1.00)	15	100%	0%	0%
Jalisco	25	3.07	(2.49)	21	100%	0%	0%	2	7.50	(3.53)	9	56%	44%	0%
Mexico City	15	2.17	(1.53)	15	100%	0%	0%	15	1.92	(0.26)	23	35%	61%	4%
Mexico State	39	2.46	(2.17)	38	63%	32%	5%	18	2.08	(1.27)	39	95%	0%	5%
Michoacán	103	3.11	(2.09)	101	80%	7%	13%	80	3.61	(1.89)	102	89%	7%	4%
Morelos	32	3.31	(3.48)	32	100%	0%	0%	1	3.00	(0.00)	32	56%	13%	31%
Nayarit	12	1.42	(0.51)	12	100%	0%	0%	8	0.85	(0.54)	12	100%	0%	0%
Oaxaca	72	1.52	(1.61)	69	86%	0%	14%	37	1.20	(0.88)	72	83%	13%	4%
Puebla	39	4.42	(5.81)	35	80%	11%	9%	16	2.23	(1.47)	38	95%	3%	3%
Quintana Roo	45	3.20	(1.84)	45	98%	0%	2%	42	2.08	(1.51)	45	76%	22%	2%
Veracruz	325	1.98	(1.79)	319	99%	0%	1%	247	1.78	(1.36)	328	81%	19%	0%
Yucatan	15	2.08	(1.02)	15	100%	0%	0%	12	0.70	(0.30)	15	73%	7%	20 %
Total	1,001	*2.27*	*(2.24)*	980	94%	2%	3%	713	*1.99*	*(1.53)*	999	*85%*	*12%*	*3%*

[a] n = total number of farmers responding to each question
[b] In Oaxaca, 323 farmers did not answer this question, accounting for the low percentage of responses (n = 713).

Of all surveyed farmers who reported on the timing of their activities, the highest percentages begin planting their operations in June (41%), begin the process to dry their grain in November (33%), and harvest in December (38%) (Fig. 2).

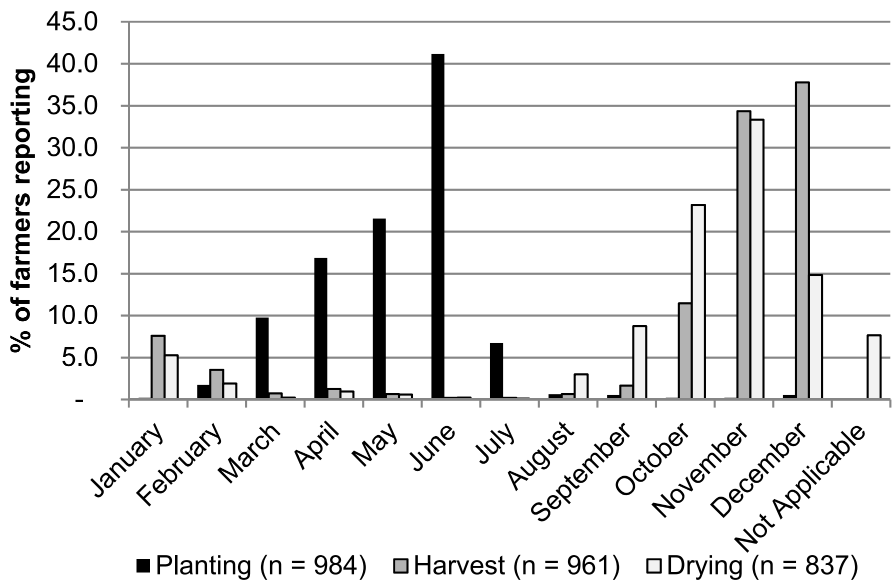

Fig. 2. Month in which farmers begin planting, harvesting, and drying (n indicates the number of farmers who responded to each question).

In total, 63% of farmers (n = 980) indicate they dry their grain in the field, 29% report drying their grain in their homes, 4% dry their grain in some combination of in the field and in their homes, and 4% report that they do not dry their grain. However, certain states dominate the different categories, with many farmers in Chiapas drying their grain in the field, and no farmers doing so in Mexico City (Table 3). Only 109 farmers responded to the question as to what their primary problem is during the process of drying, and of these 55% indicate they have no problems during drying, 25% report atypical rains, 7% indicate the maize weevil (*Sitophilus zeamais* M.) can be a problem, and the remaining 13% indicate problems with rats, robberies in the field, birds, and infestations by other insects and fungi as problems.

Table 3. Percentage of farmers reporting where they dry their grain in each state, and the percent reporting each location.

State	Total Num. Reporting	Field	Home	Both	Not Applicable
Chiapas	265	78.5%	10.6%	0%	10.9%
Guerrero	10	30.0%	60.0%	10.0%	0%
Jalisco	17	29.4%	58.8%	11.8%	0%
Mexico City	15	0%	100.0%	0%	0%
Mexico State	39	15.4%	69.2%	15.4%	0%
Michoacán	98	30.6%	61.2%	5.1%	3.1%
Morelos	32	31.3%	50.0%	18.8%	0%
Nayarit	12	0%	100.0%	0%	0%
Oaxaca	72	63.9%	33.3%	2.8%	0%
Puebla	39	38.5%	56.4%	5.1%	0%
Quintana Roo	45	95.6%	0%	4.4%	0%
Veracruz	321	73.8%	21.5%	2.8%	1.9%
Yucatan	15	100.0%	0%	0%	0%
Total	*980*	*63.1%*	*29.5%*	*3.6%*	*3.9*

The decision-making process as to when the farmers chose to harvest is extremely varied. In total, 871 farmers indicated a response as to how the decide to harvest, and of these, 42% rely on the humidity of the plant or grain (“when the plant looks dry”), 24% use a criteria related to the characteristics of the plant or grain (e.g., color or the texture of the grain when bitten), 15% rely on time (e.g., a specific amount of time after planting or depending on the phases of the moon), 8% use unspecified customs or commented they harvest based on experience, and the remaining 11% of farmers use other criteria, including when the grain can easily be removed from the cob, the sound the grain makes when it has been removed from the cob and poured, and maturity of the grain (appearance of the kernel black layer in the grain). Most of these criteria seem to be based on experience of the farmers, and not on any particular quantitative measurements (e.g., use of a humidity meter to test grain moisture). The majority of farmers harvest their grain manually (98%, n = 989), 1.6% use a method for mechanized harvesting (although what method is not specified), and the remainder use some combination of mechanized and manual harvesting.

Storage

Over 1200 farmers responded to the questions regarding the practices for storing grain, and only 9 of these farmers (<1%) indicated that they do not store grain for any reason during the year. The length of time and amount of grain stored was highly variable depending on the state, ranging from an average low of 3.43 months of storage in Mexico City, to an average of 10.60 months in Mexico State (Table 4). The quantity of grain stored is also highly variable, but the lowest average quantity (kg) stored, in Yucatan, is the same state reporting the lowest average yields (Table 2).

Table 4. Average (± standard deviation) number of months farmers report storing maize, and average quantity of maize stored (± standard deviation) in each state.

	Storage Time (months)			Maize Quantity (kg)		
State	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*
Chiapas	268	6.89	(3.34)	270	1,288	(1,063)
Guerrero	10	7.40	(2.55)	7	1,629	(816)
Jalisco	19	8.13	(2.95)	20	1,780	(1,706)
Mexico City	15	3.43	(2.01)	15	2,013	(1,689)
Mexico State	39	10.60	(6.37)	38	1,912	(1,336)
Michoacán	101	8.55	(4.01)	97	2,259	(2,086)
Morelos	32	8.06	(2.46)	32	1,626	(937)
Nayarit	12	7.92	(1.00)	12	1,175	(333)
Oaxaca	357	7.15	(3.56)	351	1,720	(1,908)
Puebla	35	8.20	(6.01)	31	3,552	(3,869)
Quintana Roo	45	8.16	(4.08)	45	1,600	(1,104)
Veracruz	320	5.52	(2.66)	313	1,190	(1,337)
Yucatan	11	6.64	(1.03)	15	947	(596)
Total	1264	*6.97*	*(3.69)*	1246	*1,569*	*(1,680)*

In the whole survey group, the most common choice of storage container is the polypropylene sack, which 34% of farmers reported using to store their grain, followed by traditional wooden structures (*trojes*), which 22% of farmers report using (Table 5). It is important to note, however, that many farmers store their grain in polypropylene sacks within the traditional wooden structures, but the numbers we report are for the method the farmer indicated, and we cannot exactly say where the polypropylene sacks would have been stored. In the case of the bulk grain, the farmers indicated simply that they stored the grain "on the floor" or "on a pallet," but did not indicate where, and in the case of the category reflecting storage "in the home," the farmers indicated that they stored their grain somewhere in their home, e.g., in the patio or in the kitchen, or simply, in the home (*casa*). Although a variety of plastic hermetic bags specifically designed for grain storage also exist, all the answers indicating the use of the plastic bag said only "plastic bag," so we cannot assume that these bags are actually those designed for grain storage. While certain technologies may not be important nationally, for example plastic or metal drums, these technologies seem to have regional importance. For example, in both Morelos and Guerrero, a high number of the farmers surveyed indicate using these containers to store their grain, and in Morelos, few farmers reported (3%) using the hermetic metallic silo.

Table 5. Percentages of the farmers reporting the use of each type of storage container in each state.

State	Total	Bulk	Drum	Hermetic Metal Silo	In the Home	Plastic Bag	Polypropylene Sack	Traditional Wooden Structure	Other [a]
Chiapas	270	2.6%	1.9%	0%	8.5%	7.0%	30.0%	49.6%	0.4%
Guerrero	10	0%	100.0%	0%	0%	0%	0%	0%	0%
Jalisco	22	0%	31.8%	0%	4.5%	9.1%	54.5%	0%	0%
Mexico City	15	0%	0%	0%	0%	0%	100.0%	0%	0%
Mexico State	39	5.1%	10.3%	20.5%	43.6%	0%	20.5%	0%	0%
Michoacán	101	5.0%	37.6%	7.9%	7.9%	3.0%	29.7%	6.9%	2.0%
Morelos	32	0%	59.4%	3.1%	0%	3.1%	15.6%	12.5%	6.3%
Nayarit	12	0%	0%	0%	58.3%	0%	41.7%	0%	0%
Oaxaca	356	0.6%	24.2%	37.4%	0.6%	1.4%	29.8%	5.9%	0.3%
Puebla	37	0%	32.4%	2.7%	5.4%	2.7%	51.4%	5.4%	0%
Quintana Roo	44	11.4%	2.3%	0%	20.5%	2.3%	25.0%	38.6%	0%
Veracruz	322	7.1%	11.2%	4.3%	5.0%	0.6%	45.0%	26.1%	0.6%
Yucatan	15	0%	0%	0%	6.7%	6.7%	0%	86.7%	0%
Total	*1275*	*3.5%*	*17.1%*	*12.9%*	*6.7%*	*2.7%*	*34.3%*	*22.1%*	*0.6%*

[a] This includes plastic bottles and water tanks, both of which were represented at less than 1% of the total individually.

To assess the baseline level of losses associated with storage, the farmers were asked about the levels of damage they estimate for various pests. Of the farmers that responded to the questions (1110), approximately 5% stated that they do not have losses during storage or that they feed damaged grain to their animals, and thus do not consider it a loss. The most common pests within all of Mexico, as indicated by the number of farmers reporting these pests were as follows: maize weevil, 86.6% of farmers indicated this as a problem (n = 1140); grain moth (Sitotroga cerealella O.), 36.9% of farmers; rodents, 34.2% of farmers; and fungus, 4.5%. Rarely, other insects, birds, and other wildlife were cited as concerns. How these various pests affect stored grain is very dependent on the state; for example, only the humid states report (high) average losses associated with various fungi (Table 6). Whereas the farmers estimate higher losses associated with the maize weevil in the central Mexican states of Morelos, Puebla, and Michoacán. Farmers in Yucatan also report high estimated average losses associated with the maize weevil, and it is important to note that they also indicated the highest rate of use of the traditional wooden structure (troje) for grain storage (Table 5).

Table 6. Average estimated percent losses attributed to common pests in each state (±sd). In the case of Total Insects, the farmers did not assign a specific percentage to individual insects.

	Maize Weevil			Grain Moth			Total Insects[a]			Rodents			Fungi		
State	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*
Chiapas	95	9.9	(9.47)	13	6.0	(3.14)	3	12.7	(8.74)	34	9.7	(5.07)	8	36.0	(28.15)
Guerrero	3	17.5	(19.84)	2	15.0	(7.07)					20.0	(0.00)			
Jalisco	14	38.9	(18.42)	2	14.0	(8.49)				1	13.3	(5.77)			
Mexico City	3	20.0	(0.00)				5	25.0	(7.07)	3					
Mexico State	21	29.1	(27.13)	17	22.9	(21.88)	9	18.3	(19.36)	4	15.8	(22.85)			
Michoacán	50	48.3	(31.56)	62	43.1	(30.33)	8	55.6	(39.77)	16	21.4	(28.22)			
Morelos	15	62.7	(40.79)	2	20.0	(14.14)	1	30.0	(0.00)						
Nayarit	12	36.3	(17.21)												
Oaxaca	120	17.4	(19.58)	25	12.0	(7.94)	48	19.3	(14.06)	17	6.9	(5.25)	31	29.1	(12.31)
Puebla	13	68.5	(35.55)	13	47.7	(32.19)				9	9.2	(9.51)			
Quintana Roo	33	34.3	(30.84)	2	20.0	(14.14)				12	19.8	(20.71)			
Veracruz	270	17.0	(12.29)	24	11.1	(5.43)				189	7.6	(9.41)	7	45.7	(15.12)
Yucatan	14	42.9	(31.73)							4	1.8	(0.50)			
Total	663	*23.1*	*(23.87)*	162	*27.6*	*(27.20)*	74	*23.4*	*(21.41)*	289	*9.3*	*(12.05)*	46	*32.8*	*(17.09)*

[a] The farmers did not assign a specific percentage to individual insects, and this may also reflect damage by other insects, e.g., the larger grain borer (*Prostephanus truncatus* H.).

In regards to any type of treatment that the farmers may apply to their grain to minimize these losses, 927 farmers responded to the question, 25% indicated that they do not apply any type of treatment (Table 7), and those that do apply a treatment provided a list of 31 different brand names of insecticides that they apply to their stored grain. Insecticides are the most common treatment (64% of farmers nationally apply some insecticide to their grain). Regionally, however, farmers favor other treatments, for example, 100% of the farmers interviewed in Yucatan apply an inert powder to their stored grain, e.g., calcium hydroxide. These inert powders have the potential to protect the grain by serving as a desiccant of insects; the fine powders enter the insect's spiracles or damage the insect's cuticle, upsetting the insects system for water balance and thereby causing death (Fields and Korunic, 2002; Upadhyay and Ahmad, 2011).

Table 7. Percentages of farmers indicating the use of different types of grain treatments in each state.

State	n	Aromatic Plants	Inert Powders and Insecticides	Inert Powders	Insecticides	No Treatment
Chiapas	246	0.4%	1.2%	1.2%	62.6%	34.6%
Guerrero	5	0%	0%	0%	60.0%	40.0%
Jalisco	16	0%	0%	0%	100.0%	0%
Mexico City	15	0%	0%	0%	100.0%	0%
Mexico State	28	0%	0%	10.7%	42.9%	46.4%
Michoacán	85	1.2%	4.7%	23.5%	63.5%	7.1%
Morelos	31	0%	0%	0%	100.0%	0%
Nayarit	11	0%	0%	18.2%	81.8%	0%
Oaxaca	174	3.4%	0.6%	4.6%	56.3%	35.1%
Puebla	18	0%	0%	0%	94.4%	5.6%
Quintana Roo	44	0%	2.3%	22.7%	68.2%	6.8%
Veracruz	240	0%	2.1%	7.1%	64.6%	26.3%
Yucatan	14	0%	0%	100.0%	0%	0%
Total	*927*	*0.9%*	*1.5%*	*8.3%*	*64.1%*	*25.2%*

Only 40 farmers (all in the state of Veracruz) responded to the question regarding what type of personal protection they use (for example, gloves or goggles) when applying an insecticide to their grain, and 100% of these farmers responded that they do not wear any type of protection. Nationally, the farmers perceive a benefit of these various treatments; in every state, the farmers report lower average estimates of losses when they use one of the aforementioned treatments (Table 8). Where the farmers do not employ a treatment for their grain during storage, they also report lower average estimations of their total losses.

Table 8. Average (±sd) estimated total losses reported for each type of treatment farmers report using, if they were to use the treatment, and without the treatment.

	Losses without Treatments			Losses with Treatment (±sd)		
Treatment	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*
Aromatic Plants	8	70.63	(40.75)	7	13.57	(9.88)
Inert Powders and Insecticides	14	53.21	(34.12)	13	8.85	(8.88)
Inert Powders	77	60.97	(32.80)	75	11.92	(12.11)
Insecticides	578	53.61	(29.58)	575	11.79	(12.55)
No Treatment	222	20.29	(17.64)			
All Treatments	*899*	*54.06*	*(31.05)*	*670*	*11.77*	*(11.48)*

End use of grain

In every state except Nayarit, the farmers sell some percentage of their grain (Table 9). Where the farmers report selling the higher average quantity of grain (Mexico City), is also where they store their grain for the shortest average number of months. The farmers interviewed also indicate that they only use polypropylene sacks for storage; the high percentage of grain sold and perhaps relatively quickly, may indicate why these farmers have never adopted other strategies for storing their grain.

Table 9. Average estimates of the volume of grain used on farm (for human and animal consumption, and for planting the next year), and average estimate of percent sold.

	Percent Consumed on Farm			Percent Sold		
State	*n*	*Avg.*	*(±sd)*	*n*	*Avg.*	*(±sd)*
Chiapas	270	87.88	(21.34)	268	12.18	(21.46)
Guerrero	10	57.00	(16.13)	9	44.44	(16.13)
Jalisco	20	70.25	(16.36)	17	18.82	(16.67)
Mexico City	15	20.67	(39.15)	15	79.33	(30.80)
Mexico State	37	75.74	(30.35)	33	19.32	(28.39)
Michoacán	91	67.97	(30.85)	88	31.65	(31.21)
Morelos	30	60.67	(46.16)	6	46.67	(32.04)
Nayarit	12	100.00	(0.00)	12	0.00	(0.00)
Oaxaca	51	83.41	(31.83)	59	6.03	(16.63)
Puebla	37	55.27	(29.08)	33	39.30	(26.26)
Quintana Roo	45	81.33	(30.35)	45	18.44	(30.00)
Veracruz	321	64.54	(28.24)	321	35.32	(28.03)
Yucatan	15	86.67	(18.39)	15	18.67	(29.00)
Total	*954*	*73.37*	*(30.48)*	*954*	*24.95*	*(28.98)*

Conclusions and future opportunities

The results we present here are in no way meant to be exhaustive regarding the many practices that smallholder farmers employ across Mexico throughout their postharvest system. However, this summary provides a baseline understanding of some of the practices in that smallholder maize farmers use for harvesting, drying, and conserving their grain in certain states, and the key sources of losses associated with these practices. These conclusions are valuable for understanding future research needs, as well as identifying the types of interventions applicable to specific regions.

It is necessary to survey more participants in states where yields are low and the number of family members is high, to ascertain how representative these results are for the state as whole. In particular, in Yucatan, farmers have an average family size of 6.2, and the lowest average estimated average yield of all of the states (0.7 t ha^{-1}). These low yields and high number of family members puts additional stress on the food security of the family, and thus adequate methods for reducing postharvest losses are all the more essential in these areas in order to preserve the quantity of grain available to the family, and that the grain is of adequate nutritional quality.

In Yucatan, Quintana Roo, and Chiapas, a high number of participants report drying their grain in the field, and in Chiapas, Michoacán, and Veracruz, the participants indicate that they do not have a specific practice for drying their grain. Considering grain humidity is one of the many factors affecting postharvest losses during storage and at other times (Ognakossan et al., 2013), appropriate methods for drying grain are essential. Drying in the field may not allow for frequent monitoring of the grain crop (depending on how far the field is from the home), and if farmers do not monitor their fields during drying, they may not be able to make management decisions if it becomes infested with any particular insects (e.g., removing the grain from the field or treatment with an insecticide). Additionally, while few farmers responded to the question regarding problems during the drying process, 25% of these farmers indicated a concern for atypical rains during drying. Not surprisingly, participants in only three states reported that various fungi are a concern during storage (with high average estimated losses in all three states), and these states are the same in which farmers seem to have less control over their drying process. Little research actually exists on the potential for pest infestations during the drying process in the field, and this is an important avenue for further research to mitigate any infestations which may occur. Additionally, new technologies for drying, for example, “mobile drying patios” which are essentially large tarps with a zipper to allow for closure during erratic rains, could be viable technologies in areas where the incidence of fungi is high. Research into adapting these types of technologies for the customs of- and time and resources available to smallholder farmers is also essential.

In regards to the various storage methods employed by the farmers surveyed, there is much room for improvement to reduce losses. The most common method employed nationally, the polypropylene sack is not resistant to many of the common pests (including rodents), and many of the farmers indicate they don’t necessarily use any type of container to protect their grain (e.g., those storing their grain in bulk, and potentially those storing their grain “in the home”). Of note regarding these practices, the state with the highest estimated use of the hermetic metal silo, Mexico State, is also the state with the highest average number of months of storage. This may indicate that the farmers here have realized the benefit of hermetic technologies for long-term storage. Also in Mexico State, more farmers report that they do not use any type of treatment on their grain, indicating that hermetic technology may have been adopted as an alternative to these treatments. However, these results may also be indicative of high investments on the part of the government or others to provide silos to farmers, and it is necessary to investigate why some states have adopted silos and other hermetic technologies at higher rates than others. Similarly, the longer storage times may be indicative of lower inherent incidences of pests, and this is another area worthy of further study.

In Yucatan, the state in which participants report high use of traditional wooden structures (*trojes*), which are typically exposed to the environment and do not prevent infestations by insects, the participants indicate a high use of inert powders to protect the grain, but did not indicate use of hermetic silos. If the low quantities of grain stored by these participants are reflective of the situation as a whole in Yucatan, this state may be an appropriate one in which to introduce small silos (1000 kg or less), and hermetic plastic bags, which can typically store 70 kg of grain or less. Because hermetic technologies work due to the absence of oxygen, it is necessary to keep the containers closed for a certain amount of time (typically three months), to allow grain respiration to reduce the quantity of oxygen within the container. At that time, any living organisms (fungus and insects) in the container are likely to die or cease development (Williams et al., 2016). As such, for farmers who frequently need to open their storage containers to obtain food for family or animal consumption, as may be the case in Yucatan where the famers consume most of their grain on0%farm, having many smaller recipients like the hermetic plastic bags instead of one large container may reduce the potential for introducing additional contaminants into the grain or augmenting the amount of oxygen in the container. Additionally, maintaining the temperature and humidity of grain, which hermetic technologies can help do, is essential for maintaining nutritional quality of the grain (Rehman et al., 2002). Further research into the habits regarding home consumption of grain could help in providing additional recommendations for storage strategies in Yucatan and elsewhere.

Finally, our survey included basic information on the percentage of grain the participants sell. However, it would be worthwhile to further investigate how farmers can improve their storage practices to take advantage of fluctuations in the prices of local markets, in order to sell grain when prices are high and potentially increase their profits. It is also essential to understand the value of hermetic technologies for preserving the quality of grain so farmers can be insured adequate compensation for their product. Such information could serve useful in the promotion to farmers of various alternatives for drying and storing grain. Overall, while the participants generally report low usage of hermetic technologies and other alternatives for reducing losses in grain quality and quantity, the results presented here indicate there many opportunities for collaborating with these farmers to develop locally adapted methods for mitigating postharvest losses.

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