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LOCAL SEED ACCESS AND EXCHANGE SYSTEMS IN THE CENTRAL HIGHLANDS OF MEXICO

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ABSRACT

In the case of maize farmers, access to seeds for planting is essential. We describe access to and exchange of maize seed in three sub-regions (central, eastern and western) in the states of Puebla and Tlaxcala, in order to analyze the use of maize seed in a rain-fed plateau region, based on local diversity. In 2013, 86 local maize producers were interviewed, 43 of whom participated in the Custodian program for the National System of Plant Genetic Resources (Sistema Nacional de Recursos Fitogenéticos), and 43 others, who did not participate, but were chosen by non-probabilistic sampling. The 86 farmers maintain 193 lots of seeds, differentiated according to grain color (white, red, blue, yellow, pinto and moradillo) and the Cacahuacintle type. There were significant differences between sub-regions in terms of access, exchange and loss of seed lots. 92.7% of the seed used in the area is native maize derived from self-sufficiency within the community or family (81.9%), with a low replacement rate (79.8%) and when a new batch of seeds is required, this is acquired within the community itself (86.0%); there is limited exchange (55.9%), between family members or close social networks. A community seed supply system prevails, due to being very accessible and people's confidence in the adaptability of the acquired genetic material, promoting *in situ* conservation of native maize; even though farmers do have access to improved varieties.

Keywords: dynamic evolution, *in situ* conservation, local seed systems, seed flow, social networks.

INTRODUCTION

In Mexico, during the period from 2018 to 2022, 6.8 to 7.4 million hectares of maize were planted; approximately 80% of these correspond to rainfed sown areas, Servicio de Información Agroalimentaria y Pesquera, (SIAP), 2023, which mainly employs native maize seed. Trueba (2012) reported that in the South-Southeast and the Altiplano of Mexico, the percentage use of this type of seed may exceed 70%; although García-Salazar and Ramírez-Jaspeado (2014) point out that during the period 2008-2012 in Mexico, 42.5% of seed used for planting maize, constituted improved seed. Perales *et al.* (2003b) indicate that farmers who use native seed usually obtain it from their own harvest and to a lesser extent from their immediate environment. Among the factors that influence the continuous planting of native seeds in Mexico are acceptance, trust, adaptation, easy access, its native origin, grain quality, ease of regional sale and other economic factors associated with costs and difficulties in accessing improved seed (Guillén-Pérez *et al*., 2002; Trueba, 2012). In relation to this last aspect, notably in Mexico, an average of 63,087 t of certified maize seed was produced annually (2003-2009), a quantity with which around 43.2 to 47% of the cultivated area can potentially be planted, as demand for native or unimproved seed constitutes up to 92,054 Servicio Nacional de Inspección y Certificación de Semillas, (SNICS), 2012; García-Salazar and Ramírez-Jaspeado, 2014). In the State of Mexico, the use of improved seeds has been encouraged and this is even reflected in state legislation (Ramírez *et al*., 2020).

Evidently, native maize populations are the product of seed lot management, as well as natural and artificial selection by the farmer, year after year.

The local seed supply system can be divided into self-generation or acquisition (flow or exchange), sowing, selection and seed storage. By means of each practice or combination of them, the farmer conserves native varieties, cycle after cycle and generates a high dynamic in the genetic structure of the cultivated populations, resulting in strong phenotypic or genetic variations (Pressoir and Berthaud, 2004a and b; Hodgkin *et al*., 2007). Seed exchange usually takes place within the same community or between communities, and social networks facilitate this process by means of transactions such as bartering, loan and return, purchasing from neighbors or in regional markets, or as donations from family or other farmers. In some cases, seeds move more than 100 km away or cross national borders (Badstue *et al*., 2006; van Etten and de Bruijn, 2007; Pautasso *et al*., 2013).

Despite their importance, local seed supply systems are not yet fully studied because they vary between agrosystems, sociocultural groups, and because they are linked to the activities of farmers and their networks or local forms of social organization (Abay *et al*., 2011; Leclerc and Coppens, 2012; Pautasso *et al*., 2013) and even vary substantially within rain-fed regions, compared to irrigation regions. Neither are its weaknesses completely understood, although some have been demonstrated, for example the small size of selected seed lots or the use of few individuals, inadequate seed health, lack of secure storage, doubts about the authenticity of seed lots and little or non-existent support for their management and conservation (Castiñeiras *et al*., 2009).

Therefore, as the local seed supply systems could be better understood, especially those grown under rain-fed conditions, we can suggest modifications, which would eventually lead to the formulation of *in situ* conservation strategies, more appropriate to local agrosystems (Ribeiro, 2019; López *et al*., 2022). In this context, the aim of this study was to analyze the use of maize seed input in a rain-fed plateau region of the states of Puebla and Tlaxcala, involving access and exchange of maize seed in three sub-regions (central, eastern and western), as relates to local diversity.

THEORETICAL FRAMEWORK

The elevated use of native or self-generated seed by the farmer is not exclusive to Mexico; Morris (2002) reported similar practices in a number of developing countries; in Latin

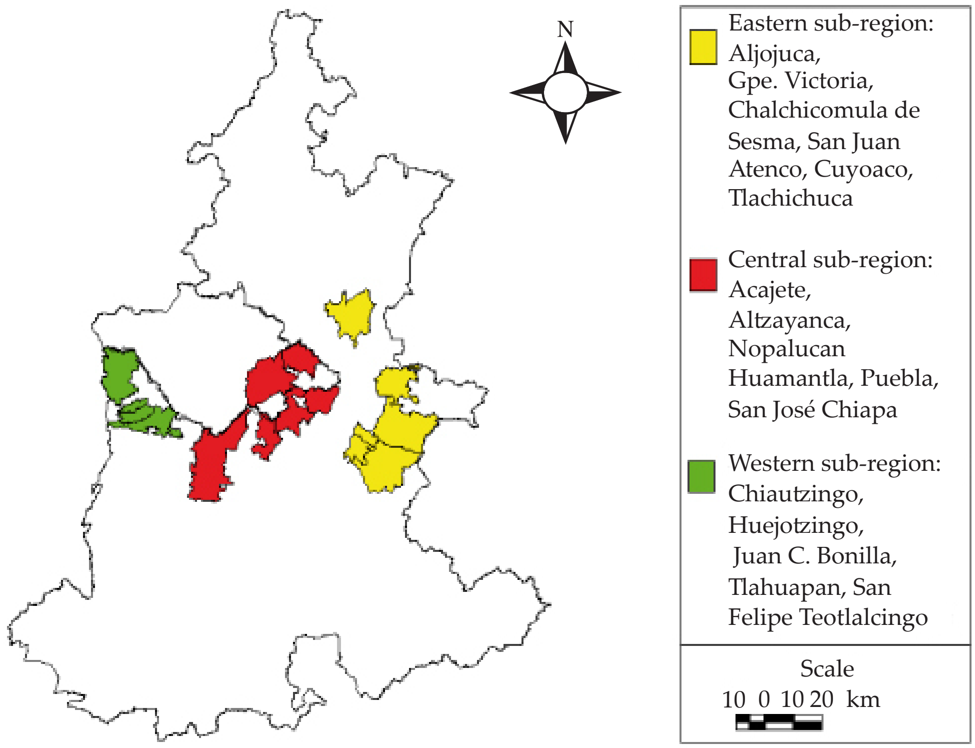
America it is used 55.1%, in Asia (not including China), 22.1%, in eastern and southeastern Africa (not including South Africa), 64.1%, in central and eastern Africa, 64.0%; this suggests that local seed supply systems are crucial elements for the *in situ* conservation of crop genetic diversity (Almekin-ders *et al*., 1994; Abay *et al*., 2011), while also influencing dynamic evolution of production (Thomas *et al*., 2011; Calvet-Mir *et al*., 2012; Fuentes *et al*., 2012). Currently there are few studies about local seed systems, except for some attempts by SNICS to assign them importance (López *et al*., 2022). In Cuba it was found that the local system ensures seed diversity, not guaranteed by the formal system and nor is the required availability or quality. In local systems, various procedures ensure seed conservation, but in most cases the seed is not produced to comply with required quality standards (Puello *et al*., 2017). However, to this day, local seed systems have enabled the continued existence of traditional production systems for small farmers, especially in rain-fed regions. For this reason, in this article, we deal with the principles of the use of local plant genetic resources, raised by the tendency towards genetic improvement and seed production in ecological niches (Muñoz, 2005), in order to analyze and describe the use of the seed in a rain-fed region, in high plateau of the states of Puebla and Tlaxcala.

METHODOLOGY

Study region

The study was carried out in 17 municipalities located in the Puebla-Tlaxcala highlands, in 15 municipalities, pertaining to the state of Puebla, to the Rural Development Districts (Distritos de Desarrollo Rural, DDR) of Cholula and Libres and also two municipalities in Tlaxcala, belonging to the DDR in Huamantla, Mexico. These municipalities are located in the high valleys, between 19° 01' and 19° 36' LN and 97° 21' to 98°33' LW. In these municipalities, during 2012, 120,215 hectares of maize were planted, of which 94.4% was grown under rain-fed conditions (SIAP, 2013); in more recent data for the same municipalities, a total harvest of 100,674 ha are reported for the 2020 agricultural cycle (SIAP, 2023), maintaining the same tendency to use native seed.

The study region was divided into three sub-regions: eastern, central and western (Figure 1). Based on previous works (Gil-Muñoz *et al*., 2004; Hortelano *et al*., 2008; Hortelano *et al*., 2012) and on information generated by the *in situ* conservation project for maize species in the National System of Plant Genetic Resources for Food and Agriculture (Sistema Nacional de Recursos Fitogenéticos para la Alimentación y la Agricultura, SINAREFI), a list of 43 maize-producing farmers was formulated, distributed within the three target sub-regions, who at some point acted as seed donors for the aforementioned projects. For each donor farmer, and by means of non-probabilistic sampling (Hernández *et al*., 2014), another farmer (from the same locality as the first), with whom there had been no prior contact but who planted maize, was contacted, forming a group of 86 farmers to whom a structured questionnaire was applied. In the eastern sub-region, 28 farmers were interviewed, in the central sub-region 22 and in the western sub-region 36.



Source: own elaboration.
Figure 1. Sub-regions and municipalities, where the study was carried out.

Structure of survey

A structured questionnaire, divided into the sections shown in Table 1, was applied. In this work, the term seed lot is used to refer to the set of grains of a specific type of maize, selected and recognized by the farmer, and used for sowing, production and seed multiplication (Louette and Berthaud, 1997).

Table 1. Structuring of the survey applied in three sub-regions in Puebla and Tlaxcala.

Variables	Type of variables
Sociodemographic data	Quantitative/Qualitative
Diversity of seed lots and farmers' access to them	Qualitative
Continuous sowing time for seed lots and native maize population production destinations, as grown by farmers	Quantitative/Qualitative
Distribution of seed lots among farmers	Qualitative
Reasons for loss of seed lots by farmers	Qualitative

Source: own elaboration.

Statistical analysis

Using information obtained from answers to questionnaires, we constructed a database organized by region, farmer and seed lot. For quantitative variables such as 'area intended for maize planting', 'estimated grain yield' and 'price per kilo of seed sold', we implemented a one-way analysis of variance. This allowed us to test the differences between sub-regions. This analysis was complemented by applying a Tukey comparison of means ($p<0.05$). For the rest of the variables, both qualitative and quantitative, which did not meet the criteria of normal distribution or homoscedasticity, a chi-square (χ^2) test was applied to test the relationships between sub-regions and descriptive variables in the local seed system (Härdle and Simar, 2007). Subsequently, a multiple correspondence analysis was carried out (Härdle and Simar, 2007), for which qualitative variables related to the exchange and supply of seeds, were used. The results from this analysis were used to generate a graph, showing the distribution of farmers by sub-regions, in two principal dimensions. All analyzes were performed using the statistical packages SPPS 19.0.0 (SPSS Inc., 2010) and SAS version 9.0 (SAS Institute, 2002).

RESULTS

The application of the questionnaire revealed a total of 193 different lots of seeds, corresponding to those planted in the three sub-regions.

Productive differences between sub-regions

Significant differences ($p<0.05$) were detected in terms of characteristics of seed supply systems between sub-regions for three quantitative variables (Table 2). Planted area and estimated production were higher in the eastern sub-region and in the central and eastern region, where the price of seed was lower.

Management of seed lots by sub-regions

The chi-square test showed a significant relationship ($p < 0.01$) between sub-regions and diversity, type of seed sown, origin and provenance, as well as transactions carried out to

Table 2. Significance of mean squares from the analysis of variance of a one-way model, and comparison of means between the sub-regions of Puebla-Tlaxcala.

Sources of variation and regions of comparison	Sown area (ha)	Estimated production (t)	Price of seed sold (pesos/kg)
Mean squares of study regions	59.481*	7.161**	123.494**
Comparison of study sub-regions:			
Western	2.200b	2.590b	5.570a
Central	3.600ab	2.420b	3.670b
Eastern	3.910a	3.070a	3.070b

*Significant differences at $p<0.05$; **Significant differences at $p<0.01$. Means with the same letter in columns are statistically equal (Tukey, $p<0.05$).
Source: own elaboration, with data from the study.

obtain seed lots (Table 3). Meaning that in principle there are general mechanisms for access or supply of seed by farmers, but they differ between sub-regions; for example, even though all the farmers interviewed indicated that they plant mainly white or cream, blue and red maize grain, the number of lots of red maize in the western region was higher than that at other sites and other types of maize were identified there, for example pinto and moradillo.

In the three sub-regions, the names used by farmers to designate their seed lots essentially describe the color of the grain (white, blue, red, yellow, moradillo or pinto), apart from the term "cacahuacintle", which refers to a species of maize mainly used to make pozole. The term "criollo" is used to differentiate native material from the improved type (Table 3) and more than 92% of the seed lots used for planting correspond to native or creole maize populations, for which farmers are usually self-sufficient, although they may also obtain it from their family or neighbors, in the same town or nearby municipalities. These practices indicate that regional maize production is supported by the planting of native

Table 3. Diversity of seed lots and access to them among farmers from three sub-regions of Puebla-Tlaxcala.

Questions/answers	Sub-region			Observed frequency (% of total)
	Eastern	Central	Western	
Seed lots identified by the farmer (χ^2=301.2**, n=193)				
White or cream	40	23	28	91 (47.2)
Blue	22	14	23	59 (30.6)
Red	0	2	13	15 (7.8)
Yellow	7	5	8	20 (10.4)
Cacahuacintle	5	0	0	5 (2.6)
Pinto	0	0	1	1 (0.5)
Moradillo	0	0	2	2 (1.0)
Prevalence of type of seed sown (χ^2=306.7**, n=193)				
Native or Creole	71	42	66	179 (92.7)
Improved	2	2	5	9 (4.7)
Origin of seed lot sown (χ^2 =194.0**, n=188)				
Own or family	54	37	63	154 (81.9)
Other farmers	19	7	6	32 (17.0)
Origin of seed lot sown (χ^2=421.7**, n=188)				
Same location	48	43	61	152 (80.9)
Neighboring community, same municipality	8	0	2	10 (5.3)
Community in a different municiality	15	1	6	22 (11.7)
Type of transaction to obtain a seed lot (χ^2=289.5**, n=188)				
Family donation or loan	25	27	33	85(45.2)
Purchase from neighbor/other	33	14	16	63 (33.5)
Purchase from commercial outlet	1	2	11	14 (17.4)
Exchange	7	0	6	13 (6.9)

**Significant differences at p≤0.01 level (χ^2 test).
Source: own elaboration, with data from the study.

populations, with seed that is multiplied and selected by the farmers themselves, who have preserved the same lots continuously for periods of one to 30 years (Table 4). Among the arguments for the preservation of this type of seeds were that they are traditionally planted and because of existing demand in the regional market (Table 4), which indicates that production is intended for both self-consumption and sale in regional markets.

Seed lots are not regularly replaced and when there is replacement, it most often occurs among farmers in the eastern sub-region, in the state of Puebla (Table 4).

Generally, in the three sub-regions, 55.9% of the total seed lots are subject to exchange between farmers. This exchange is carried out regularly within the community, through sale, gift or exchange for another batch of seeds, either between families or within the closest social networks (Table 5).

The largest proportion of seed lots come from the community itself, which confirms a low exchange of seed lots between farmers from neighboring communities or other municipalities. More than 50% of farmers in the sub-regions declared having lost a batch of maize seed during the time they have been sowing this cereal. The presence of droughts and frosts were the main causes for seed loss in the three sub-regions.

Table 4. Continuous sowing periods of seed lots and production destinations of native maize populations, cultivated by farmers from three sub-regions of Puebla-Tlaxcala.

Questions/answers	Sub-region			Observed frequency (% of total)
	Eastern	Central	Western	
Continuous sowing of a seed lot (χ^2=169.4**, n=188)				
1-10 years	50	16	24	90 (47.9)
11-20 years	6	6	9	21 (11.2)
21-30 years	9	13	23	45 (23.9)
31-40 years	5	6	6	17 (9.0)
41-50 years	2	1	5	8 (4.3)
Reasons for planting seed lots (χ^2=375.1**, n=188)				
Tradition	39	24	53	116 (61.7)
Market demand	21	15	8	44 (23.4)
Curiosity	1	3	7	11 (5.9)
Loss of desireable characeristics	8	2	0	10 (5.3)
Replacement of seed lots (χ^2=929.6**, n=193)				
Not undertaken	48	41	65	154 (79.8)
Every year	8	2	5	15 (7.8)
Every 2 years	7	0	0	7 (3.6)
Every 3 years	7	1	0	8 (4.1)
Destination of grain production (χ^2=203.2**, n=188)				
Own consumption	12	16	17	45 (23.9)
Market	9	1	3	13 (6.9)
Both	52	27	51	130 (69.1)

** Significant differences at $p \leq 0.01$ level (χ^2 test).
Source: own elaboration, with data from the study.

Table 5. Distribution of seed lots among farmers in three geographic sub-regions of Puebla-Tlaxcala.

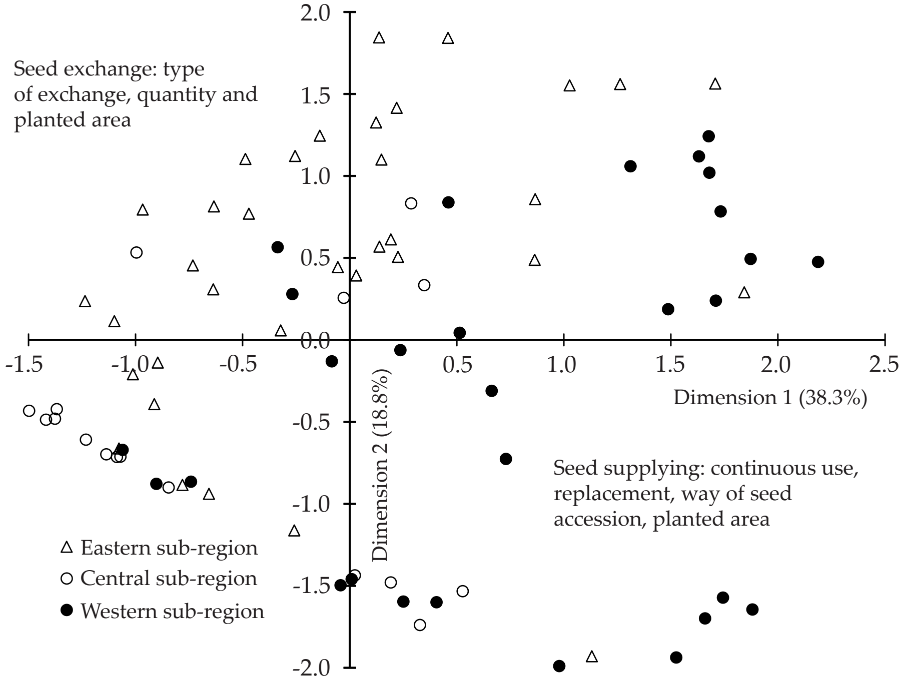
Questions/answers	Sub-region			Observed frequency (% of total)
	Eastern	Central	Western	
Seed supply among farmers, number of lots (χ^2=85.8**, n=188)				
Seed lots provided	36	20	49	105 (55.9)
Seed lots not from exchange	37	24	22	83 (44.1)
Destination of the exchange of seed lots between farmers (χ^2=85.5**, n=193)				
No seed provided	38	24	24	86 (44.6)
Provided to family	2	10	33	45 (23.3)
Provided to neighbor	12	4	7	23 (11.9)
Provided to aquaintance	11	5	8	24 (12.4)
Origin of farmers for whom seed was provided (χ^2=220.8**, n=107)				
Same community	25	19	48	92 (86.0)
Community in another municipality	9	1	0	10 (9.3)
Transaction used to provide seed (χ^2=158.7**, n=107)				
Sale	33	12	31	76 (71.0)
Exchange for another seedlot	3	3	11	17 (15.9)
Gift	0	3	7	10 (9.3)

**Significant differences at P≤0.01 level (χ^2 test).
Source: own elaboration, with data from the study.

When farmers lose a seed lot, they indicated that they can obtain a similar type from their family, neighbors or acquaintances; usually within the same community or occasionally from another municipality. Furthermore, because most of their sowing depends on the rainy season (93.6%) they only trust local or regional seed lots because they perceive their greater adaptive potential and because they originate from the community. This indicates that the informal seed system in the sub-regions is demarcated, as they only rely on their own native gene pools.

Types of seed supply and exchange

Types of seed supply and exchange were described as greater for the informal seed system in the central region. We obtained an 81.6% explanation of total variation as far as the fourth principal dimension. The first dimension (38.3%) was associated with seed supply; its main variables were years of continuous use (eigenvector coefficient for this factor = 0.0478), replacement (0.209), planted area (0.088) and forms of transaction to obtain seeds (0.041). Then, the area planted with each seed lot (coefficient of the eigenvector for this factor=0.136), the recipient of the seed lot (0.103), transactions (0.114) and sale price (0.415), to a greater extent explained the second dimension (18.8%), which can be classified as referring to seed exchange. Based on the two aspects previously described, the interviewed farmers were located (identified by sub-region), in order to generate Figure 2. Here, local seed management practices by sub-regions are worth defining, as in the western sub-region supply was decisive, whereas in the eastern and central area, types of seed exchange were more indicative.



Source: own elaboration.

Figure 2. Distribution of farmers in the principal two dimensional plane for the multiple correspondence analysis, according to the local seed system (n= 92), in three sub-regions of Puebla and Tlaxcala.

DISCUSSION

An average of 2.24 seed lots per farmer was found in the three sub-regions; to date there has been no specific estimate of the number of seed lots or varieties of maize managed by farmers in rain-fed areas, only reference to the ample diversity of maize pertaining to ecological niches and reflected in the varietal pattern (Muñoz, 2005; Gil, 2006) for this niche. This panorama can be considered representative of the maize-producing regions in the high valleys of Puebla and Tlaxcala, with tendencies towards the use of native or creole seed, rather than certified or improved seed (Trueba, 2012; García-Salazar and Ramírez-Jaspeado, 2014), with greater variation found in seed lots of special maize, especially of pigmented type, in the western region. The classification or perception of distinctiveness between seed lots can be assumed to be generic because contrasting aspects of grain color are differentiated, as opposed to particular plant characteristics, grain dimensions or cobs (Gibson, 2009); however, it is a common classificatory expression among Mesoamerican maize producers to refer to their native varieties, in which the white color is usually the most common (Louette and Smale, 2000; Perales *et al.*, 2003a and b; van Etten and de Bruin, 2007). However, this does not imply that they do not differentiate their varieties by other plant characteristics; grain, cob or types of use in Mexican cuisine (Soleri and

Cleveland, 2001; Perales *et al*., 2003a and b), as is the case of cacahuacintle maize, clearly identified by its type of grain and mainly used to make pozole; we should reevaluate and give credit to this observation on the part of farmers (Silva, 2019). The study region comprises the center of origin and diversification of maize species in the Mexican highlands (Vigouroux *et al*., 2008) and various local and regional articles (Gil-Muñoz *et al*., 2004; Hortelano *et al*., 2012; Alvarado-Beltrán *et al*., 2019) have documented the existence of great genetic diversity of maize in the state of Puebla and in the high valleys of this state. These results also show that even when farmers in the center of Puebla and Tlaxcala have access to seeds of improved varieties, as reported by Morris (2002), SNICS (2012) and Trueba (2012), they prefer to plant their native populations; thus the genetic diversity of native maize continues to be preserved *in situ*.

The documented exchange pattern indicates that the informal seed supply system is decisive in maintaining both maize diversity and grain production. The same practices have been referred to in various works related to local maize seed supply systems (Latournerie *et al*., 2004; Castiñeiras *et al*., 2009; Puello *et al*., 2017). However, it is difficult to separate the cultural aspects from the social aspects related to the preservation of genetic diversity and the exchange of seed lots, where social networks used by each farmer intervene (Calvet-Mir *et al*., 2012; Leclerc and Coppens, 2012; Pautasso *et al*., 2013). Farmers in the western zone mentioned that when it comes to requests from their relatives, they feel morally obliged to provide the seed they require, a fact that was also documented among farmers in the Central Valleys of Oaxaca (Badstue *et al*., 2006). These same practices affecting maize seed sources were also documented for the Chimaltenango region, Guatemala (van Etten and de Bruin, 2007).

Acquisition of seed lots mainly comes from the community itself, confirming a low exchange of seed lots between farmers from neighboring communities or other municipalities, as reported by Castiñeiras *et al*. (2009) among traditional maize producers in Mexico, Cuba and Peru. Louette and Berthaud (1997) and Perales *et al*. (2003b) indicated similar patterns in communities in Jalisco and the central highlands of Mexico, respectively.

The causes or reasons for loss of seed lots recorded in this study differ from those documented by Perales *et al*. (2003b), who highlight the wrong season of the year, damage by pests and rotten or small ears, among other reasons; our results show that the most common problems for the loss of seed lots are droughts and frosts, conditions that often occur in the Altiplano.

According to Brush *et al*. (1988), the maize diversity preserved by each family or community depends on various factors such as: rate of natural inbreeding between neighboring plots, agro-ecological diversity of crop fields, natural biological adaptations to abiotic or biotic stress, artificial selection and diversity maintenance by farmers. All this happens, if each farmer sows, selects, stores, multiplies and shares the genetic diversity that he possesses with his neighbors, through the local seed system. It has been shown that forms of preservation and also exchange of seed lots between farmers, have strong implications in terms of the population dynamics of maize genetic diversity; for example, as the farmer replaces or loses his seed lots, genetic erosion occurs (van Heerwaarden *et al*., 2009). However, in this work it became apparent that even when there are losses of seed lots due to factors such as drought or frost, the same seed or another very similar one can be obtained from the farmer's family members or neighbors and acquaintances; a situation that provides the local system with a strong capacity of resistance or resilience. In other cases, the local seed system has the capacity to cushion the negative effects of climate, thanks to high rates of recombination, which is a product of genetic flow, mediated by the transmission of pollen or seed exchange between farmers, which may have greater beneficial effects, as the system is regulated in a rational way (Bellon *et al*., 2011; Wagner-Medina *et al*., 2020). In other regions, inbreeding between hybrids or improved varieties and native populations has been documented, which promotes the generation of favorable genetic combinations, adapted to the farmer's agrosystems (Bellon and Berthaud, 2005; Bi-tocchi *et al*., 2009). Finally, it is notable that in the eastern and central sub-regions, the exchange of seeds was more important, whereas in the western sub-region, the seed supply system was more definitive; the latter being where there was greater diversity of maize, especially pigmented types.

CONCLUSIONS

The seed supply and exchange system in the central highlands of the states of Puebla and Tlaxcala, in Mexico, is a closed system, in the sense that the germplasm mainly circulates within the same communities and between farmers' neighbors or relatives; however, it has some characteristics of an open system, in that the circulation of germplasm does not respond to legal provisions on seed distribution, but rather to the immediate needs of the resource by farmers. This seed supply system constitutes a mechanism that favors and promotes the *in situ* conservation of genetic diversity in maize, as this diversity is directly related to environmental, management and use conditions faced by the farmer in each agricultural region. Finally, the community dynamics that intervene in the conservation of various seed lots or native maize diversity are part of the strategies of social groups for access to natural resources, as a means to ensure family food security.

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