Pathogen mitigation in an Ecuadorian potato seed system: Insights from network analysis

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Summary

The structure of seed systems has important implications for how likely they are to effectively supply high quality seed to communities of farmers. We evaluated seed system networks defined by a regional potato farmer consortium (CONPAPA) in Tungurahua, Ecuador. Networks were structured around farmer seed and potato transactions and their sources of information about pest and disease management. We performed a scenario analysis of disease spread that takes into account interacting biophysical, socioeconomic and informational elements. CONPAPA provides training, seed improvement and potato processing and marketing for its members. The high centrality of CONPAPA in the network means that disease management interventions, such as training, monitoring and variety dissemination should target CONPAPA staff and processing facilities. The market in Ambato, the largest nearby town, was the next most useful place to monitor. Farmers reported receiving advice about disease and pest management through trusted CONPAPA technical staff. Local agricultural stores were also reported as providing advice to many farmers, but were viewed by farmers as significantly less reliable. Training of store owners could provide one way to improve outcomes in this seed system. Farmer access to information (number and quality of sources) was equal for both genders. Female farmers had a smaller than expected amount of the market share, however. In CONPAPA there is 47% adoption of improved seed, much higher than the 2% rate reported for Ecuador in general. This is probably improving yields significantly for small farmers in the consortium. Agricultural seed systems and network analyses provide one window into a variety of global change phenomena encompassing environmental and societal concerns.

Keywords: seed systems, potato, complex systems, seed degeneration, disease management, pest and diseases, seed networks, multilayer networks

Introduction

Networks of crop seed distribution are an important lens through which we can evaluate the ecology and spatial distribution of crop plant genotypes. Seed systems are human mediated seed dispersal networks that support plant based agricultural production. Seed systems encompass biophysical elements as well as all the stakeholders and activities that support the system, including interacting scientific (e.g. breeding), management (e.g. agricultural practices, integrated pest management) and regulatory aspects (e.g., *Dickeya solani*; Thiele 1999). Thus, seed systems are best understood as a network of contextually interacting biophysical and socioeconomic elements (Leeuwis and Aarts 2011). Only the regulated aspects of a system would be considered a part of a "formal" system. Seed systems share many traits with other managed ecological systems in which there are larger-scale human institutions driving some system components and individual land managers who make choices about a smaller unit of the landscape (e.g. farmers or conservation managers). Institutional interventions can affect systems indirectly and directly via policy, training, funding or direct management. The relationship between institutional interventions and on the ground management may be more or less predictable, depending on adoption by land managers.

Seed (including vegetative planting material) is both the basic input and an output for plant-based agricultural systems. As a carrier of genetic information, seed systems provide a way to predict and influence the ecology, structure, composition, and productivity (e.g., yield) of agroecosystems at all scales. Knowing about crops and their seed systems can also be predictably linked to human-mediated environment modifying behaviors. This is because specific management interventions are commonly associated with any given crop's cultivation (e.g. irrigation, fertilizer, pest or disease management interventions). Much of the work carried out by seed system stakeholders relates to providing disease free, high quality seed to farmers. This is achieved by improved seed processing, multiplication, storage and distribution. Another important role for scientists involves developing desirable and disease resistant varieties for dissemination through the system. In short, many environmental and biological constraints on crop productivity can be predicted, reduced or removed by understanding and modifying seed systems. By understanding these systems, a scientist can make meaningful links between ecological patterns at a variety of scales and many of the socioeconomic factors that may influence them. Here we use epidemiological network analysis (Shaw and Pautasso 2014) of a potato seed network to understand and predict disease risk.

Where seed systems work well, farmers have access to the seed of productive varieties that is not infected by pathogens. However, efforts to create new seed systems have often been unsuccessful, especially in developing countries (Jaffee et al. 1992, Thomas-Sharma et al. 2016). Understanding the structure and function of seed systems can support more sustainable seed systems. Aspects that determine seed system utility, sustainability, and resilience include access to and availability of seed, seed quality, variety quality (adapted, disease resistance, and matching user preferences), affordability, and profitability (Sperling et al. 2013).

Seed system resilience is tested most when there are significant stressors or crises, be they environmental, biotic (e.g. pathogen outbreaks) or socioeconomic (McGuire and Sperling 2013). Though broad categories of threats are predictable, some events may be viewed as crises because they are spatially varied, temporally unpredictable, and may have multiple distinct drivers (e.g. pathogen, drought, conflict and economic crises). Formal seed systems can be “static and bureaucratic” (Lybbert and Sumner 2012) while farmers and markets may be quite adaptable. Single optimal solutions are unlikely. Many development agencies orient their interventions toward the development of demand-driven systems that support a for-profit model of seed supply, believing them more sustainable and resilient (McGuire and Sperling 2013, Sperling et al. 2013), but governments and aid agencies continue to play important roles. A common belief is that diversity improves resilience, in terms of crops and varieties, or supply channels (McGuire and Sperling 2013). Clearly short and long term planning could be required to meet challenges, and stakeholders need to be flexible to strike a good balance between sustaining and transforming systems (McGuire and Sperling 2013). Trade-offs are likely, with interventions under one scenario or set of stressors potentially being counter indicative in another scenario, or for some stakeholders (McGuire and Sperling 2013).

There is a risk that pathogens can move through a seed system network. Detection of pathogens in the network in a timely manner could allow for mitigation measures to be implemented. Important hubs in the network are obvious points of risk for disease spread but peripheral nodes could be the first to see an invasion. Strategies for dissemination of resistant varieties may need to change depending on network properties. In addition, the spread of endemic diseases like *Rhizoctonia*, or the potential arrival of emerging diseases from distant locations (Czajkowski et al. 2011, van der Wolf et al. 2014, Czajkowski et al. 2015) can be modelled and mitigation strategies tested using a multilayer network analysis (Garrett 2012, 2017).

Our objectives in this analysis are as follows:

1. Characterize a representative potato seed system in Ecuador, in terms of its strengths and vulnerabilities with respect to disease management and socioeconomic measures.
2. Develop a risk metric for disease vulnerability of individual network nodes and examine their utility as control points for pathogen mitigation measures.

3. Use scenario based multilayer network analysis to evaluate how systems like this Ecuadoran seed potato system could be improved.
4. Determine whether gender biases exist in network transactions or access to information.

Materials and Methods

Study system: the CONPAPA potato seed system in Tungurahua, Ecuador

There are approximately 50,000 ha of potato in Ecuador, with 97% of this area located in the Andes, and 87.5% of farms being less than 10 ha in size (Devaux et al. 2010). Storing potato is uncommon in Ecuador given that it is possible to produce tubers all year, and the market expects fresh potatoes for consumption (Devaux et al. 2010). Seed is typically reused. This makes potato subject to seed degeneration and associated yield loss (Thomas-Sharma et al. 2016). The National Research Institute INIAP (*Instituto Nacional de Investigaciones Agropecuarias*) produces formal basic potato seed. However, only 2% of the seed used in Ecuador originates at INIAP (Devaux et al. 2010). Two preferred cultivars for farmers in the Ecuadorian Andes are INIAP-*Fripapa* and *Superchola*. However, farmers also grow many other cultivars, such as INIAP-*Gabriela*, INIAP-*Catalina*, *Diacol-Capiro*. Seed produced by INIAP starts from pre-basic seed, which are mini-tubers produced from *in-vitro* plants. Basic seed, the next generation, is multiplied in the field by INIAP or associated farmers. The next three generations of seed include the following three seed categories–registered seed (*semilla calidad I*), certified seed (*semilla calidad II*), and selected seed (*semilla calidad III*)–and are produced in the field by seed producers. Trained seed producers form a part of the Consortium of Potato Producers (CONPAPA) and produce seed for member farmers. The yield increase associated with each of these three categories is reported to be 17%, 11% and 6%, respectively, compared to the seed produced by the farmers in the informal system (Devaux et al. 2010), although yield declines attributed to seed degeneration of ca. 30% were regarded as conservative (Thomas-Sharma et al. 2016).

A recent study in Ecuador reported 29% of yield loss were attributable to virus-based seed degeneration (Panchi et al. 2012). Viruses such as *Potato virus Y* (PVY), *Potato virus X* (PVX) and *Potato leafroll virus* (PLRV), are major causes of seed degeneration in many parts of the world (Salazar 1996, Frost et al. 2013). However, depending on the geographical region, fungi, bacteria, nematodes, phytoplasmas, and insects can also play important roles in potato seed(Thomas-Sharma et al. 2016). In high-elevation potato production regions of Ecuador, *Rhizoctonia solani* is a major cause of seed degeneration (Fankhauser 2000), while in many tropical and subtropical countries, *Ralstonia solanacearum* is a major concern (Mwangi et al. 2008). Adding to this complex etiology, the rate of degeneration is also highly variable across geographical regions. Factors such as host physiology, vector dynamics, environmental variability, and the choice and success of management strategies can affect the rate of degeneration (Thomas-Sharma et al. 2016)In high elevation regions for example, lower temperatures can limit vector activity and pathogen multiplication while also influencing host physiology that limits pathogen transmission into daughter tubers(Bertschinger 1992). Evidence suggests virus transmission to daughter tubers is usually incomplete with between 30 and 75% of tubers being infected (Bertschinger et al. 2017). Similarly, the application of management strategies such as resistant varieties, certified seed material and other on-farm management strategies, individually and/or collectively, can affect the spread of disease epidemics in a region

(Thomas-Sharma et al. 2016). A better understanding of these inter-related factors can thus greatly improve seed degeneration management in a geographical region.

Established in 2006, CONPAPA has a membership of ca. 300 farmers in central Ecuador (principally in Tungurahua, Chimborazo and Bolivar). This organization is the current realization of various aid and governmental efforts to improve livelihoods for small potato farmers (Kromann et al. 2017). It aims to support small farmer associations that produce seed potato and potato for consumption, through training, provision of certified seed, and by processing and marketing produce. It cleans and processes produce (e.g., for chips and fresh potato) in a regional processing facility in Troje south of Riobamba in Ecuador. It also sells potato on behalf of members. Production of table potato in CONPAPA ranges between 15 and 20 metric tons per hectare, with production levels being influenced by management, variety, time of year, and the origin of the seed. Average production reported by CONPAPA is higher than the 9.5 metric tons per hectare reported for Ecuador as a whole (Devaux et al. 2010). CONPAPA in Tungurahua reported (www.conpapa.org) that it supplies more than 25 tons per week to meet market demand.

Survey methods

This study focuses on 48 farmers that are members of CONPAPA in the Tungurahua district. This is 66% of the 72 heads of households registered in this region (Monteseodeoca, pers. comm.). However, the 48 farmers in this study represent a census of all the active farmers at the time of this study. Farmer network sizes and farmer activity can change as farmers opportunistically pursue a variety of alternative livelihoods from year to year, e.g., construction or service jobs, in response to changing conditions (in good and bad years; Violon et al. 2016). A questionnaire was completed by scientists via on-farm voluntary interviews of 48 farmers in the CONPAPA district of Tungurahua over 10 days in November and December, 2015. In addition to demographic information, the questionnaire documented farmers' reported seed sources, varieties planted, volume bought and price paid for the last three planting periods. Information was also collected about the sale or use of potato for food, including destination, variety, volume and price received. Information was recorded about the principal diseases that the farmers dealt with, and the pesticides used to treat them. Farmers were also asked to describe their sources of advice regarding integrated pest management and the confidence they had in that advice. In some cases, the transaction information provided by farmers recorded that there was a transaction, but did not include volume or price information.

Data analysis and modeling

Seed and potato transactions between the farmers and other stakeholders were analyzed via network analyses using igraph (Csárdi and Nepusz 2006) in the R programming environment (R Core Team 2016). Transaction volumes, prices with respect to variety, and farmer gender were summarized and examined statistically. The frequency with which common pests and diseases were reported by farmers, including those responsible for seed degeneration, are reported overall and by gender.

Disease spread was simulated across the seed and potato network such that the probability of infection was moderated by farmer ability to respond effectively, this being dependent on their knowledge about pest and disease management (IPM). During the survey interviews, farmers described their sources of information for pest and disease management, and the trust that they placed in these. Disease spread was modeled as a function of the number and quality of information sources about IPM. The idea is that a well-informed farmer (with high node in-degree in communication networks, or with highly trusted sources) will be less likely to be a point of disease establishment (probability set to 0.8 to the power of the number of sources).

This simulation generates an estimate of the number of nodes infected before the disease will be detected at each potential sampling node, given a random starting node. The output allows us to estimate relative risk in terms of the number of nodes that would be infected if you were to monitor only the node in question.

Results

Seed system: overview

The seed system in this study is centered around CONPAPA, which provides and receives seed and products from member farmers (Figure 1). A total of 1157 quintals (100 lb bags) or 52 (*t*; metric tons) of seed was reported as used by farmers, CONPAPA provided 47%, and 36% was self-supplied or reused seed, while the remaining 16% came from other sources. CONPAPA was reported as receiving only 7 *t* of seed from male farmers (trained seed multipliers) in the network. No females provided seed to CONPAPA. Farmers reported a total of 503.9 *t* potato being sold with CONPAPA getting 414.7 *t* (82%) of potato (28% of this was from female farmers). Farmers reported selling 85.3 *t* directly to local markets, one farmer reported selling 3.2 *t* directly to a restaurant. It is important to note that 262 transactions were reported but interviewees did not provide volume or price information for 71 and 58 of transactions respectively (including self-supplied seed transactions). Of the 47 farmers that reported buying or selling potato or seed, 18 were female. On a per transaction basis there was a difference between the volume of potato product sold by male (mean=165 quintals) and female farmers (mean=97 quintals; t-test, p-value = 0.05). There was no difference for per seed transactions for male and females with means of 11.9 and 8.3 quintals respectively (t-test, p-value=0.09).

Unreported here is the movement of pre-basic seed to CONPAPA from INIAP. CONPAPA in Tungurahua may also receive seed from CONPAPA multipliers outside of the region.

Seed system: analysis by variety

Overall, while farmers used on average two varieties, the median use was just one. In other words, about half of the farmers used a single variety, while the other half used 2,3,4 or 5 different types. Ranking the use of varieties by the numbers of farmers using them matches almost exactly the ranking by number of transactions per variety (Table 2), which suggests that the high number of transactions of the main varieties is not driven by a single farmer or group of farmers trading them amongst themselves. The 3 most used varieties, according to these criteria, are Superchola (33% of farmers use it, its product transactions represent 36% of all transactions, and its seed transactions 32%), Fripapa (17%, 20%, 22%) and Puca (13, 10, 10), in respective order of ranking.

A second comparison of the total volume of transactions by variety, shows that the three most frequently exchanged varieties are also the ones with most transacted volume (Table 3). Indeed, Superchola's transacted volume represents 40% of all volume transacted in terms of product and 35% in terms of seed. Fripapa's seed volume transacted is higher than the product volume transacted 26% vs. 21%). Finally, Puca variety volume represents 9% in terms of product and 7% in seed. Interestingly, two varieties that are not used by a majority of farmers --Carrizo and Victoria—represent 8 and 7% in terms of volume transacted, almost as much as Puca. Finally, the percentage of volume transacted of Unica's seed is larger than Puca's seed volume (9%) and Natividad is as large as Puca's (7%).

IPM information

Farmers largely reported obtaining information about integrated pest and disease management (IPM) from CONPAPA (mean in-degree was 3.5 overall; Figure 2). There was no difference (t-test, p-value=0.39) between male (3.7) and female (3.2) in-degree with respect to number of information sources reported. Importantly farmers frequently reported receiving information from agrichemical stores (green squares in Figure 2). Family members also provided important sources of information about IPM (Figure 2). Women reported husbands as a source of information for IPM, but no men reported that their wife was a source of IPM information. Farmer assessed trust levels could range between zero and five. Mean trust levels reported by men (3.4) and women (3.8) was not significantly different (t-test, p-value=0.08). The main sources of information were CONPAPA and stores, the mean trust level farmers reported for all stores was 3.01 and 4.4 for CONPAPA (t-test, p-value=1.873e-07). The internet was reported as an important source of information for just one farmer.

The most frequently reported diseases and pests were late blight, Andean potato weevil, and potato black leg. Viruses were not reported, or were considered unimportant by 99% percent of farmers (Table 1). Slugs and leafminers were more frequently reported as a problem by female farmers than males, though rates were low (Table 1).

Disease risk in the system

Under the various scenarios we evaluated (Figures 3 A-C), CONPAPA is obviously the most effective place to monitor in order to detect a disease before it has spread far. This reflects its central role in the network. Similarly, several stakeholders and farmers at the periphery of the seed and potato network tend to be poor locations for detecting potential disease in every simulation. This is mostly because they only provided seed rather than receiving seed or product (yellow), or had low in-degree (orange or light orange; Figures 3 A-C). Weighting risk of establishment based on the quality of the information sources about IPM causes some nodes at the periphery some nodes become more important for monitoring (colors are yellow in the equal weight scenario (Figure 3 A) versus darker orange (Figure 3 B and 3C). In the scenario where farmer ability to prevent establishment was weighted by the number of sources of information (Figure 3 C), we find that “Market1” becomes a good point for monitoring as disease travels less distance before being detected. This is the market in Ambato Ecuador which is the largest town in the region and has the highest reported in-degree of any of the markets.

Discussion

In this analysis, we demonstrate an approach for identifying priorities for monitoring plant health in seed systems. In this relatively simple seed system, disease monitoring at CONPAPA processing facilities should be a high priority for detection of incipient disease. Secondarily monitoring at the market in Ambato could also be relatively effective. Similarly, mitigation measures during a disease outbreak, such as dissemination of new resistant varieties, or training would best focus on these nodes in the network. Network models provide a window into epidemiology of plant diseases and efficient sampling for plant epidemic surveillance (Chadès et al. 2011, Sutrave et al. 2012, Hernandez Nopsa et al. 2015, Thomas-Sharma et al. 2016). An important observation is that despite evidence from other studies suggesting 30% declines in yield attributable to virus infection of seed in Ecuador (Panchi et al. 2012), only one farmer reported it as a concern. It remains an open question the extent to which viruses are reducing yield in this region, or if they are simply understudied.

A surprising number of agricultural stores are providing IPM advice and related products. Importantly, and perhaps with good reason, farmers do not report trusting them as a source of information compared to technical staff working for CONPAPA. Clearly training store owners about pest management could be an effective measure to improve management outcomes for farmers inside and outside of the consortium. We modelled disease spread as a function of farmer information quality and sources with respect to IPM. This usefully marries management and informational networks with the biophysical network (seed network and disease epidemiological models). There were no significant differences in gender access in terms of the number of information sources, or the trust they placed in their information sources.

A focus on the seed and potato *transaction* network is a place to good start for disease models. This is because most viruses are transmitted to daughter tubers and will be hitchikers for each transaction. A more nuanced approach could take into account the observation that daughter tuber transmission is incomplete and infection and spread rates are different at low versus high altitude (Bertschinger et al. 2017). Node vulnerability to infection should also be modeled in terms of specific diseases and scenarios should account for varietal differences in resistance. A key point to consider for potato seed systems is transmission mechanisms. A case in point, *Potato virus X* (PVX) and *Andean potato mottle comovirus* (APMoV) are transmitted by contact while others such as *Potato virus Y* (PVY) and *Potato leafroll virus* (PLRV) are vectored by aphids (Fankhauser 2000). Networks should include both transaction based spread and the spatial proximity of farms one to another. Also, this network does not include all the farmers in CONPAPA's other three regional centers, or non-CONPAPA farms. Network dynamics change from year to year, so scenarios should consider temporal dynamics (e.g. between good and bad years; Violon et al. 2016).

The seed system for CONPAPA has been described as a mixed formal and informal system (Kromann et al. 2017). The system here can be characterized as predominantly formal with the reported formal seed sources accounting for 47% of the seed in this study mean time between seed replenishment reported to be approximately 3 seasons. This is much better than the 2% formal seed sources reported for Ecuador in an earlier study (Devaux et al. 2010).

We evaluated the CONPAPA structure as a first step to support improved sampling, IPM, risk assessment for pathogen and pest movement, and farmer decision-making. Identification of key control points that influence the success of seed systems (e.g., farmers, farms, information sources) supports enhancement of the system (e.g., maximizing the distribution of new seed varieties using fewer distribution channels, managing disease outbreaks, and targeting improvement of communication and infrastructure). Resources can be invested in particular nodes to improve practices, control pest and disease outbreaks, leading to improvements in the seed system. We present initial results for CONPAPA as part of an ongoing project to develop general recommendations for improving seed system structure.

Seed systems and network analyses provide one window into global change phenomena encompassing environmental and societal concerns. The adoption of formal seed systems is inherently a risk avoidance measure that aims to increase productivity and improve economic outcomes for farmers, but the implications are wide reaching. This is because global change is often mediated through agricultural practices, development and trade. Links are easily made between seed systems and land use changes, biodiversity, climate change, invasive species, and disease impacts. Network analyses and a systems approach can be used to understand interacting biophysical, socioeconomic and informational elements and put management interventions in their proper context.

Authors' contributions

JH-N collected data and wrote the article, CB wrote the article, and carried out analyses, PK and JA-P helped collect data, facilitated logistics in Ecuador, PU helped with questionnaire design and provided an economic perspective, ST-H provided background about seed systems, KG designed the study, wrote the article, carried out simulations, and mentored authors.

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Figures

Figure 1. A seed system transaction network with links (line thickness) weighted by the volume of potato and seed (bought, sold, used or traded) by 48 farmers associated with CONPAPA in Tungurahua, Ecuador. Black lines are seed, gray lines represent potato for food consumption. Self-loops represent seed produced on-farm. Volume units were in quintals (largest volume reported in a transaction was 900 quintals, lowest was 1). Dotted lines represent transactions where volumes were not reported.

Figure 2. A network depicting farmer-reported information sources for pest and disease management (IPM). Line thickness ranges between 1and 5 and represents the reported level of trust that the farmer has in that source of information.

Figure 3. Disease invasion is simulated with initial infection starting at a random node and proceeding through the network defined by farmer transactions for seed (black) lines and potato (grey) –line widths are scaled to volumes but do not affect the simulation. The risk at each node ranked in terms of the number of nodes that would become infected before the disease if you were to select that node for monitoring. Monitoring a low risk node (blue) would mean that only a small number of nodes become infected before you detect the disease at that node. Three scenarios were run where the probability/risk of the disease starting at a given farmer node is weighted differently for 3 A) all farmers are equally likely to be a source of spread; 3 B) risk depends on the maximum quality of information per the IPM information network in Figure 2; and for 3 C) risk decreases based on the number of information sources (node in-degree not including loops) as depicted on the IPM information network in Figure 2.

Fig. 1

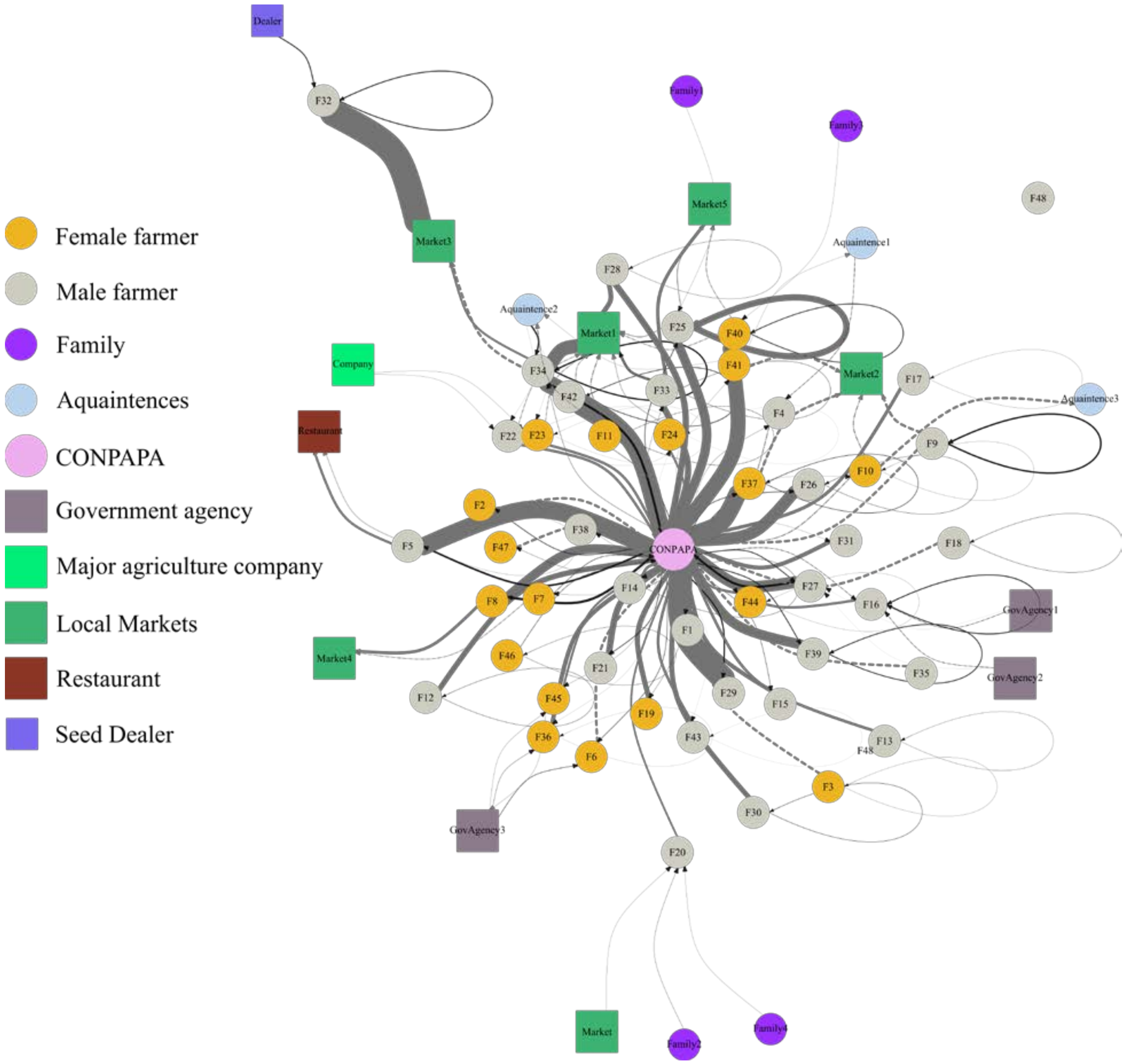

Female farmer
Male farmer
Family
Aquaintences
CONPAPA
Government agency
Major agriculture company
Local Markets
Restaurant
Seed Dealer
Dealer
Company
Restaurant
Market1
Market2
Market3
Market4
Market5
Market
GovAgency1
GovAgency2
GovAgency3
Aquaintence1
Aquaintence2
Aquaintence3
Family1
Family2
Family4
CONPAPA

Figure 2

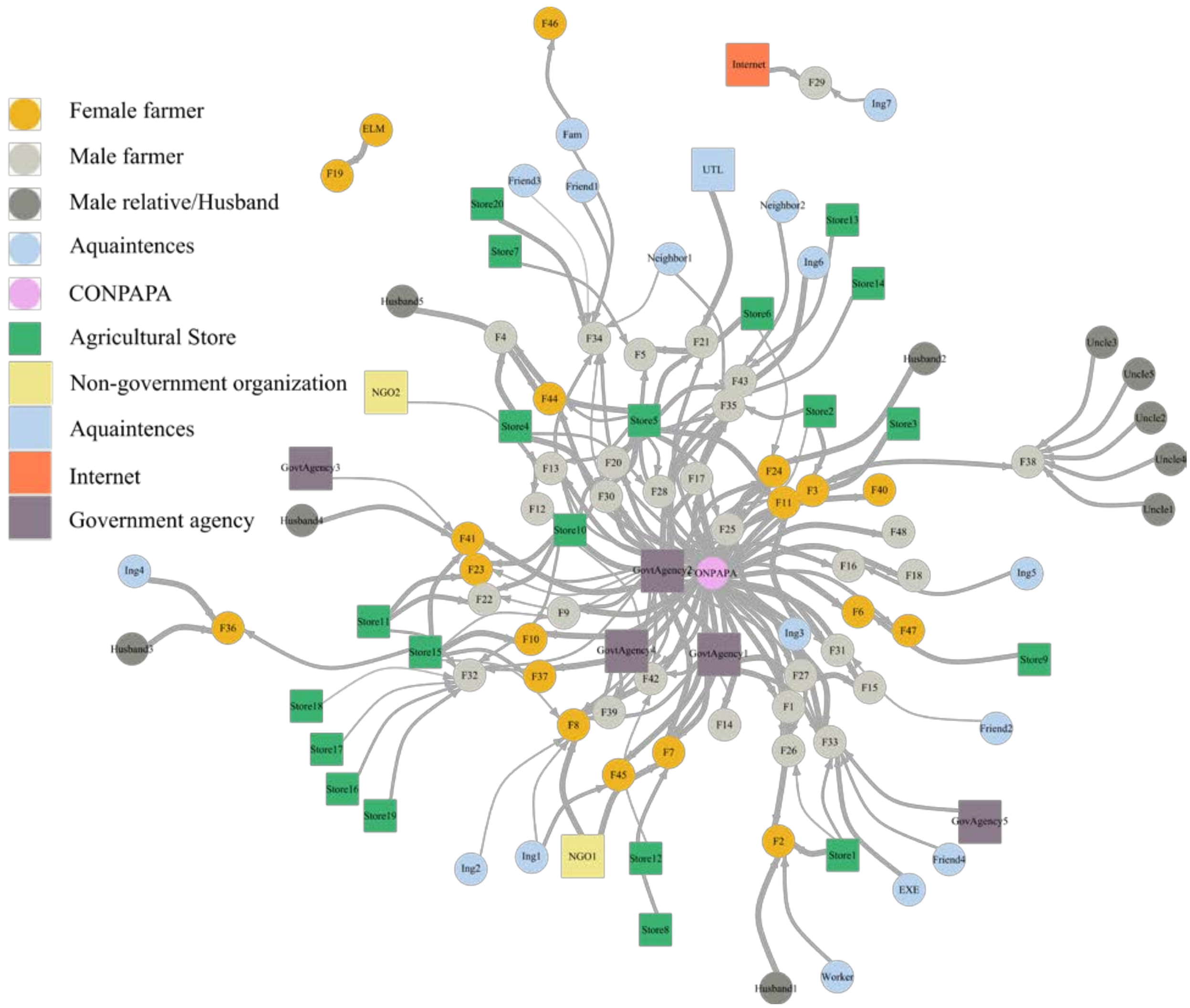

Female farmer
Male farmer
Male relative/Husband
Aquaintences
CONPAPA
Agricultural Store
Non-government organization
Aquaintences
Internet
Government agency
Internet
UTL
NGO1
NGO2

Figure 3 A

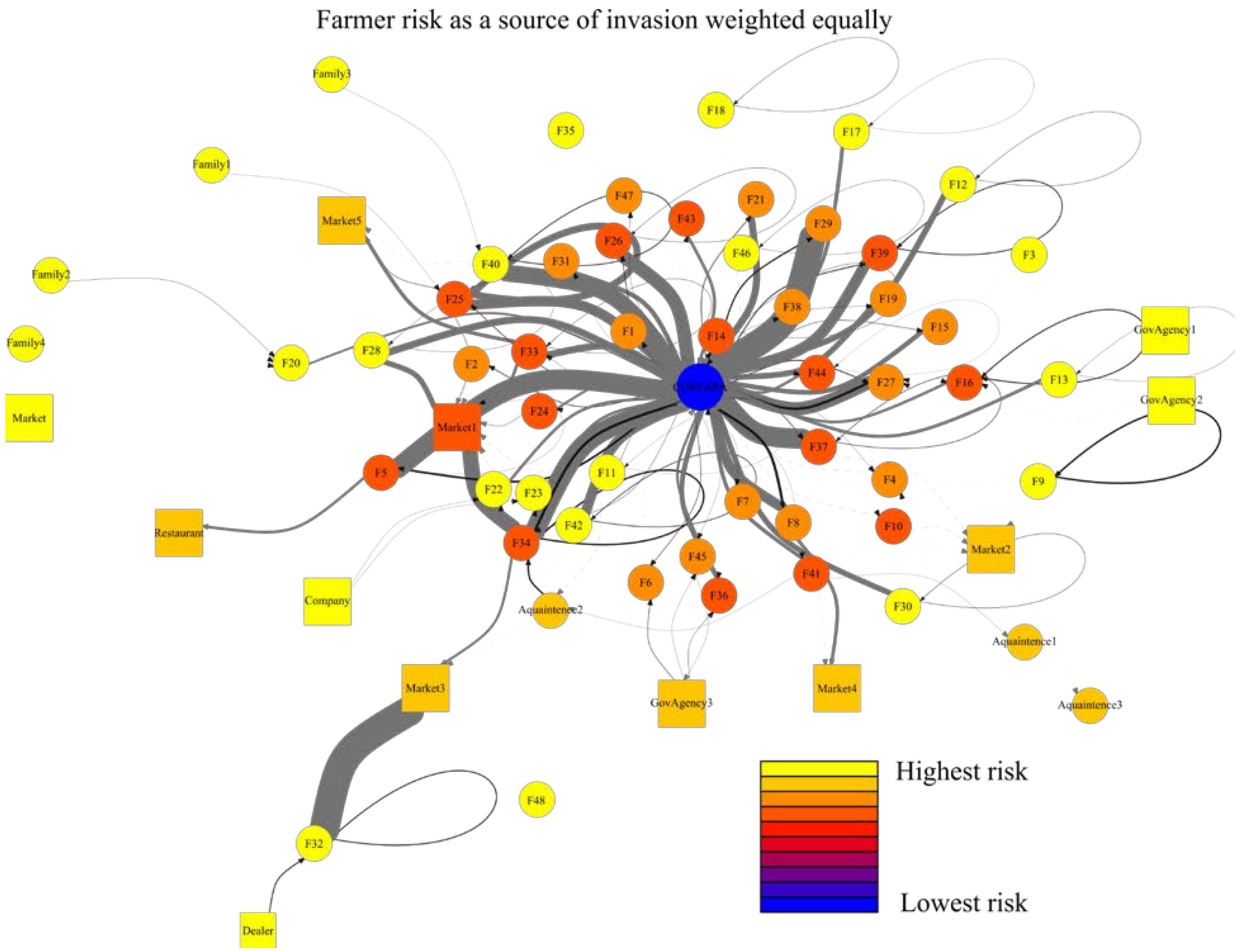

Farmer risk as a source of invasion weighted equally
Family3
F18
F35
F17
Family1
F12
F47
F21
Market5
F43
F29
F26
F39
F3
F46
F40
F31
Family2
F25
F19
F38
F15
F1
F14
GovAgency1
Family4
F28
F33
F20
F2
F44
F27
F16
F13
GovAgency2
Market
F24
Market1
F37
F5
F11
F4
F9
F22
F23
F7
F42
F8
F10
Restaurant
Market2
F34
F45
F41
F6
F36
Company
Aquaintence2
F30
Aquaintence1
Market3
GovAgency3
Market4
Aquaintence3
Highest risk
Lowest risk
F48
F32
Dealer

Figure 3 B

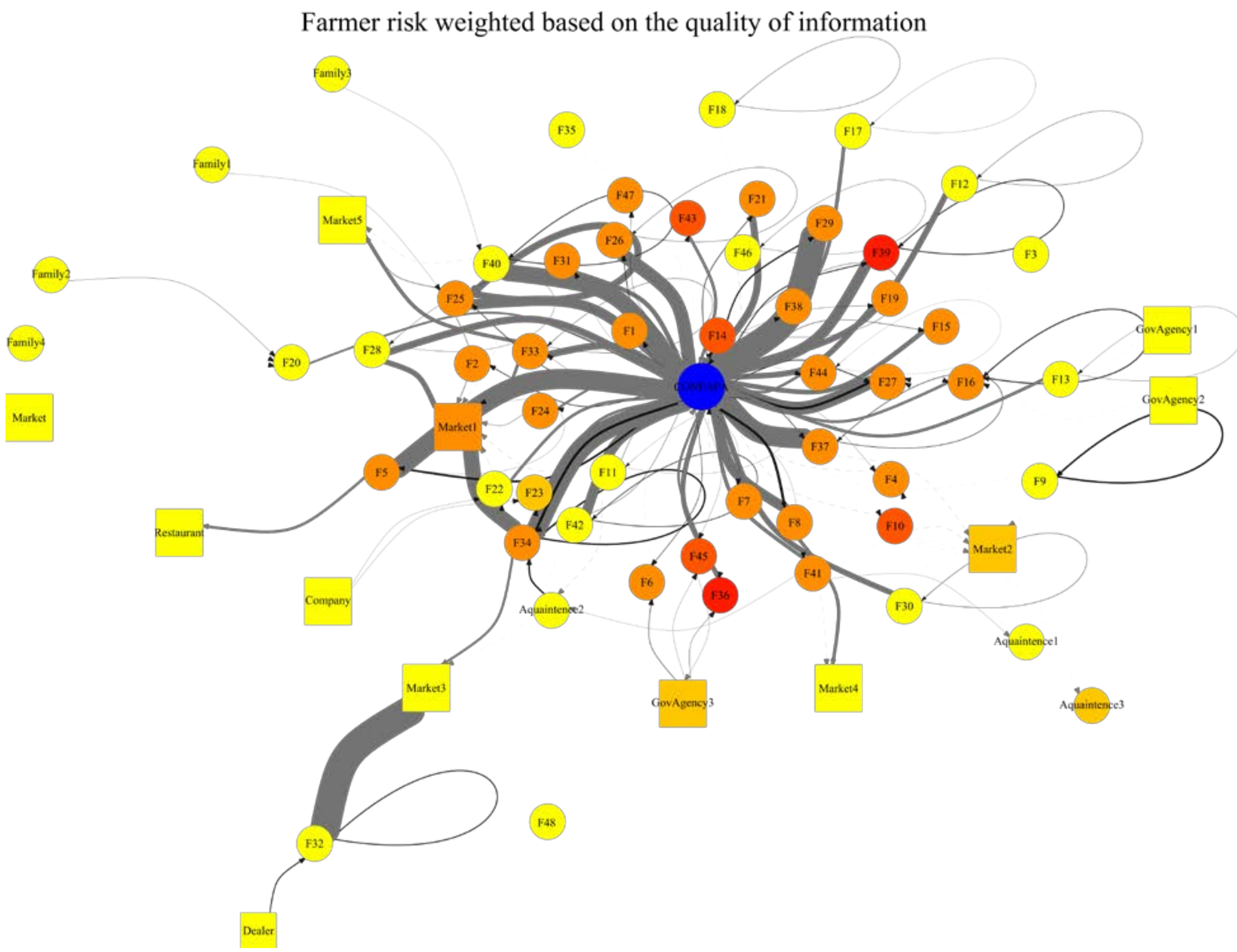
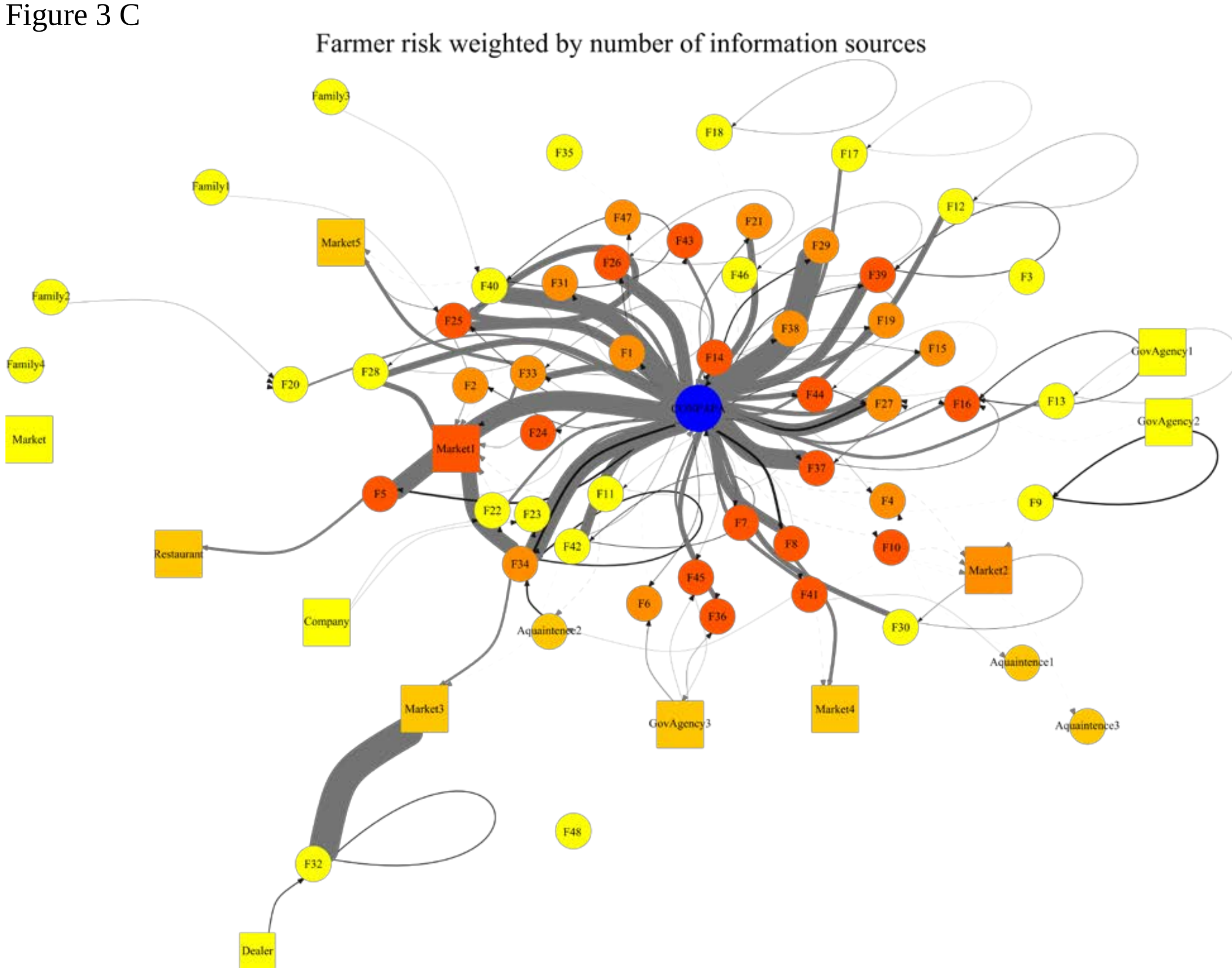

Farmer risk weighted based on the quality of information
Family3
Family1
Family2
Family4
Market
Market5
Market1
Market2
Market3
Market4
Restaurant
Company
Dealer
GovAgency1
GovAgency2
GovAgency3
Aquaintence1
Aquaintence2
Aquaintence3

Figure 3 C


Farmer risk weighted by number of information sources
Family3
F18
F35
F17
Family1
F12
F47
F21
Market5
F43
F29
F26
F39
F3
F40
F31
F46
Family2
F25
F38
F19
F15
F1
F14
GovAgency1
Family4
F28
F33
F20
F2
F44
F27
F16
F13
GovAgency2
Market
Market1
F24
F37
F5
F11
F4
F9
F22
F23
F7
F8
F10
Restaurant
F42
Market2
F34
F45
F41
F6
F36
Company
Aquaintence2
F30
Aquaintence1
Market3
GovAgency3
Market4
Aquaintence3
F48
F32
Dealer

Tables

Table 1. Frequency of pests and diseases reported by male and female farmers in Tungurahua, Ecuador. Pests and diseases known to cause seed degeneration are indicated.

Pathogen/disease or pest	Degenerative	Females reporting	Males reporting	% farmers
Phytophthora infestans (late blight)	Yes	15	30	94
Premnotrypes spp. (Andean Potato Weevil)	Yes	10	26	75
Rhizoctonia solani (Potato black leg)	Yes	7	16	48
Puccinia pittieriana (Common rust)	No	6	12	38
Epitrix spp. (Potato flea beetles)	Yes	3	9	25
Phtorimaea operculella, *Symmestrichema tangolias, Tecia solanivora* (Potato moths)	Yes	4	4	17
Fusarium spp.(Fusarium rot)	Yes	1	6	15
*Liriomyza spp.** (Leaf miner)	No	5	2	15
*Slugs**	No	4	0	8
Frankliniella tuberosi (Thrips)	No	2	1	6
Nematodes	Yes	1	1	4
Spongospora subterranean (Powdery scab)	Yes	1	1	4
Septoria lycopersici (Annular leaf spot)	No	0	1	2
Viruses	Yes	1	0	2
White fly	No	1	0	2

Pair of values within a column (by gender and by number of plots) followed by (*) are significant different according to the Chi square test (a=0.05, df=1)

Table 2. Varietal use in terms of transactions and number of farmers using.

	Total transactions	Seed		Product		Nr Farmers using the variety	
Superchola	**90**	**40**	32%	**50**	36%	31	33%
Fripapa	**56**	**28**	22%	**28**	20%	16	17%
Puca	**27**	**13**	10%	**14**	10%	12	13%
Yana	**17**	**9**	7%	**8**	6%	8	8%
Unica	**16**	**7**	6%	**9**	7%	6	6%
Carolina	**13**	**6**	5%	**7**	5%	4	4%
Victoria	**10**	**4**	3%	**6**	4%	4	4%
Gabriela	**8**	**3**	2%	**5**	4%	3	3%
Chaucha	**7**	**4**	3%	**3**	2%	3	3%
Carrizo	**6**	**3**	2%	**3**	2%	**2**	2%
Suprema	**4**	**2**	2%	**2**	1%	2	2%
Americana	**2**	**1**	1%	**1**	1%	1	1%
Natividad	**2**	**2**	2%	**0**	0%	1	1%
Norteña	**2**	**2**	2%	**0**	0%	1	1%
Tulca	**2**	**1**	1%	**1**	1%	1	1%

Table 3. Volume of seed and product exchanged (with percentages).

	Total Volume				Vol per trans	
	Product		Seed		Product	Seed
Superchola	**4580**	40%	**425**	35%	**143**	**11**
Fripapa	**2405**	21%	**323**	26%	**172**	**15**
Puca	**999**	9%	**80**	7%	**111**	**7**
Carrizo	960	8%	66	5%	480	22
Victoria	760	7%	48	4%	190	12
Unica	600	5%	116	9%	200	19
Carolina	470	4%	79	6%	118	13
Yana	350	3%	43	3%	58	5
Gabriela	90	1%	6	0%	45	3
Chaucha	80	1%	16	1%	27	5
Suprema	15	0%	21	2%	15	11
Americana	0	0%	1	0%	.	1
Tulca	0	0%	0	0%	.	.
Natividad		0%	90	7%		45
Norteña		0%	0	0%		.