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Pests and diseases affecting potato landraces and bred varieties grown in Peru under indigenous farming system

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Summary

The major pests and diseases were identified and quantified on thirteen potato landraces and three bred varieties cultivated in Peru. Late blight (*Phytophthora infestans*) was the primary biotic constraint affecting plants before flowering with an average severity of 24%. No other pathogens caused severe foliar disease, but black scurf (*Rhizoctonia solani*) was relatively common on tubers of some genotypes with incidence ranging from 4.30 to 33.33%. The viruses most generally considered important in potato seed degeneration, PVY and PLRV, were extremely rare, with 1.11 and 0.12 % incidence, respectively. Other viruses considered mild, such as PVX and PVS, were more common, with incidence of 28.23 and 22.29 %, respectively. Potato flea beetle (*Epitrix* spp.), potato leaf beetle (*Diabrotica* spp.) and Andean potato weevil (*Premnotrypes* spp.) were common, with incidence of 28.14, 18.75 and 13.61%, respectively. Potato landraces known as Ishkupuru, Lengua de vaca, Chaulina, Chaulina Tajacaja and Negro cayash were identified as potentially resistant to *P. infestans*.

Additional key words: Potato landraces, indigenous farming system, pests, resistance.

Resumen

Las principales plagas y enfermedades de papa en el Perú fueron identificadas y cuantificadas en trece variedades nativas y tres variedades mejoradas. El tizón tardío (*Phytophthora infestans*) fue la principal limitación biótica que afecta a las plantas antes de la floración con una intensidad promedio de 24%. No hay otros patógenos que causan severos daños foliares, pero la costra negra (*Rhizoctonia solani*) fue relativamente común en los tubérculos de algunos genotipos de papa con incidencias que oscilan entre 4.30% y 33.33%. Los virus generalmente considerados como los más importantes en la degeneración de semilla de papa, PVY y PLRV, fueron extremadamente raros, con una incidencia 1.11 y 0.12%, respectivamente. Otros virus considerados leves, como PVX y PVS, fueron más frecuentes, con una incidencia de 28.23 y 22.29%, respectivamente. La pulguilla de la papa (*Epitrix* spp.), el escarabajo de la hoja (*Diabrotica* spp.) y el gorgojo de los Andes (*Premnotrypes* spp.) fueron frecuentes, con una incidencia de 28.14, 18.75 y 13.61%, respectivamente. Las variedades nativas de papa conocidas como Ishkupuru, Lengua de Vaca, Chaulina, Chaulina Tajacaja y Negro cayash fueron identificados como fuentes potenciales de resistencia a *P. infestans*.

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Palabras claves adicionales: Papas nativas, sistema tradicional de cultivo, plagas, resistencia.

Introduction

A landrace is considered as an indigenous cultivated potato (Spooner *et al*., 2005) which has a high capacity to tolerate biotic and abiotic stress resulting in a high yield stability and an intermediate yield level in a low input agricultural system (Zeven, 1998).

Of the 3.500 potato landraces maintained by the International Potato Center (CIP) at its headquarters in Lima, Peru, almost 2.000 were collected in Peru (Huamán, 2001). Farmers in the departments of Huanuco, Junin, Pasco and Huancavelica produce the greatest number of potato landraces under an indigenous farming system called "'Chaqru" in the Quechua language, which involves planting mixed stands of native bitter landraces for freeze-drying, or mixed stands of native floury landraces for fresh consumption, which often contain various species with different ploidy levels (de Haan *et al*., 2009; Zuñiga and Rojas, 2011). Through strategic alliances among public and private institutions in the Andean region, potato landraces have been reassessed in the last decade as a cultural heritage. Furthermore, technical assistance in development projects have enabled farmers in Peru to increase yields from 12 to close to 14 t ha^{-1} (Ordinola, 2010). Despite these efforts, pests (arthropods) and pathogens, such as the Andean weevil (*Premmnotrypes* spp.) and *Phytophthora infestans*, the cause of late blight, appear to be increasing their damage in potato landraces (Hofmaster, 1979; Pellegrini, 2013; Zuñiga and Rojas, 2011). Other pathogens (mainly viruses) affect tuber health status causing "seed degeneration" (Bertschinger *et al*., 1990; Jeffries, 1998; Tsror *et al*., 1999; Fankhauser, 2000) , but these viruses are generally not taken into account by farmers during cultivation, nor when selecting seed (Urrea, 2011). In the Andean countries, farmers generally select and store seed from one season to the next. Rarely, they may have a special seed plot, but more commonly they separate part of their harvest for seed (Thiele, 1999). There is evidence that producing seed at higher altitudes can reduce the level of viral infection (Thiele, 1999), but with climate change the incidence of virus vectors will increase at higher altitudes, which may diminish beneficial effects of high-altitude production on seed quality (Giraldo *et al*., 2010; Salazar, 1995). Integrated Pest Management (IPM) technologies have been developed to control different pests and diseases; however these technologies have not been widely adopted by Andean farmers for many reasons, including too few extension personnel, limited geographic coverage of extension systems, insufficient training materials and poor transportation infrastructure (Ortiz *et al*., 1999). Future efforts to design new extension interventions should be based on a quantification of the pest and disease problems facing Andean farmers at present. However, little is known of the incidence and severity of pests and diseases in this region, particularly in traditional landraces. The objective of the present work was to identify and catalogue the main pests and diseases affecting potato grown under ancestral planting systems in Peru and estimate the severity of the damage caused by these organisms, the following objective was to characterize the phenotypic expression of resistance to *P. infestans* in potato landraces obtained from subsistence farmers' collections.

Materials and Methods

Farmers' fields

Sampling was done in nine fields belonging to subsistence farmers located between 3,718 and 4,090 m above sea level, in the district of Yanacancha (between 10° 37' to 10°39 ° SL), which is in the department of Pasco (Table 1). The surface areas of the selected plots ranged between 193.20 and 1,482m^2. These farms in the central highlands of Peru were selected because they utilize the Chaqru indigenous farming system (de Haan, 2009). In this indigenous farming system, potato is planted after several years of sectorial rotation and fallow. The agro-ecosystem in this region is known locally as "Suni", and is characterized by cool conditions, where the average daily maximum temperature is about 15 °C, and rainy weather during the potato growing season from October to April (Pulgar-Vidal, 1996). Observations on incidence and severity pests and pathogens were made between November 2009 and May 2010.

Table 1. Characteristics of plots in the Peruvian highlands were potato plants were assessed for incidence and severity of pests and diseases.

Place	Plot	Altitude (masl)	South Latitude	West Longitude	Total area by plot (m^2)
Quinua	1	3,894	10°37' 19.90"	76º 10'25.18"	880.00
Quinua	2	3,900	10°37' 20.46"	76 10' 25.22"	783.80
Quinua	3	3,718	10°37' 21.22"	76º 10' 25.78"	1747.30
Quinua	4	3,793	10°37' 16.07"	76º 10'25.81"	193.20
Quichas	5	4,007	10°38' 10.66"	76º 10'21.78"	663.40
Quichas	6	4,002	10º 39' 11.86"	76º 10'22.72"	440.60
Quichas	7	3,972	10º 37' 10.68"	76º 10'21.40"	408.00
Quichas	8	3,975	10º 37'10.63"	76º 10'21.14"	1482.30
Candelaria	9	4,090	10º 36' 76.60"	76º 10'24.56"	1172.00

[a]All fields were located in the district of Yanacancha, in the department of Pasco. Each plot was managed by a farmer using local production practices.

Landraces and bred varieties

Farmers had previously identified the potato landraces and bred varieties planted in mixture in each plot. Hereafter we also use the term genotype to refer to either a potato landrace or bred variety. In the Chaqru farming system seed tubers are maintained by the farmers from season to season and the potato landraces identified in the plots had from 8 to 25 years of self-supply seed production, while the bred varieties had 7- 8 years of self-supply (Table 2).

Table 2. Names of potato landraces and bred varieties assessed on farmers' fields in the Peruvian highlands for incidence and severity of pests and diseases and of those used in an on-farm evaluation of host plant resistance against the potato late blight pathogen, *Phytophthora infestans.*

Incidence and severity of pests and diseases			Screening for resistance to *P. infestans*		
Variety	**Type [a]**	**Seed age [b]**	**Variety**	**Type [a]**	**Scale value[c]**
Alianza	L	10 -15	Milagro	L	15.85 a
Ambar	L	12 – 15	Niño runtush	L	14.93 b
Blanca	L	8 -12	Rurun shasha	L	12.99 b
Chata negra	L	15 -20	Cunchucano	L	11.96 c
Wayro rojo	L	12 -18	Peruanita	B	10.07 c
Wayrush	L	12 – 16	Wayro	L	7.25 d
Ishkupuru	L	15 – 18	Puca chollo	L	6.57 d
Lengua de vaca	L	15 -20	Canchan	B	9.00 d
Liberteña	B	7 – 8	Puca wayro	L	6.44 d
Muru Wayro	L	15 – 18	Amarilla tumbay	B	6.36 d
Negra	L	18 -25	Yana wayro	L	6.32 d
Peruanita	B	12 – 15	Negro cayash	L	4.74 e
Putish	L	15 – 20	Chaulina tajacaja	L	3.64 e
Juito	L	10 -15	Chaulina	L	3.23 d
Juito Amarillo	L	9 -10	Serranita	B	1.94 f
Yungay	B	7 - 8	Venturana	B	0.77 f

[a] L= Potato landrace or B= bred variety

[b] Years of on-farm seed multiplication - origin of seed prior to this is unknown

[c] Scale value calculated according to Yuen and Forbes (2009); in this scale, 9 is considered highly susceptible. Scale values followed by different letters are significantly different (Duncan’s 5%).

Origins of seed stocks acquired by these farmers were not known but in the case of bred varieties may have come from the national certified seed system. In the case of landraces, seed had probably been acquired locally within the informal seed system (Thiele, 1999).

Foliage Evaluation

A total of 736 plants were selected at random among all genotypes in all selected plots. The number of selected plants per plot varied according to the area of each plot (between 30 and 100). The selected plants were grouped according their morphologic characteristics. Incidence and severity of disease and pest damage were evaluated only one time on each plant just before flowering. Multiple evaluations were not made due mainly to the difficulty in accessing to the field plots and the associated costs. The period just prior to flowering was considered optimal of a single point evaluation to allow pest and pathogen buildup while avoiding confounding effects of plant aging.

Incidence was measured as the percentage of all sampled plants affected with a particular disease or pest damage in relation to the total number of plants sampled of the same genotype. Severity was estimated as the proportion of tissue per plant affected by a particular disease or pest and was averaged over all plants of the same genotype affected by specific disease or pest. To confirm the identity of certain causal agents (especially fungi), leaf samples were collected and placed in moist chambers to stimulate sporulation and facilitate diagnosis. Infected tissue areas bordering on healthy tissue were cultivated in Potato – Dextrose – Agar (PDA) and Vegetable V-8 Agar (V-8) emended with antibiotics when microscopic evidence was absent. The identification of fungal pathogens was based on standard taxonomic keys.

To confirm pest identification, different insect life stages (egg, larvae, pupae, or adult) were monitored on the plants, soil or debris, and then were related to damage caused on leaves according to reports in specialized potato guides (Wale *et al*., 2008; Hooker, 1981).

Tuber Evaluation

Tubers were harvested individually from plants evaluated for foliage symptoms and taken to the International Potato Center (CIP) laboratories in Lima, Peru for the evaluation. The tubers were washed with running water and dried with paper towels, after which they were evaluated for incidence and severity of specific potato diseases or damage caused by pests. To confirm pathogen identity, infected tissue areas bordering on healthy tissue were isolated using Potato – Dextrose – Agar (PDA) or Kelman (K) culture media and Crystal Violet Pectate Medium (CVP) for fungi and bacteria, respectively in order, especially. The identification of pathogens was based on standard taxonomic keys. To confirm pest identification, larvae were monitored on the tubers, and then were related to damage caused on tubers according to reports in specialized potato guides. Incidence was measured as the percentage of all tubers affected with a particular disease or pest damage in relation to total tubers of the same genotype. Severity was estimated as the proportion of tissue (surface or internal tissue) per tuber affected by a particular disease or pest and averaged among all tubers of the same genotype affected by specific disease or pest.

Diagnosis of viruses

One tuber from each selected plant was chosen at random among all tubers harvested and subjected to temperature fluctuations (8 to 20 °C every two weeks during two at three months) to induce sprouting. The apical bud from each tuber was then extracted aseptically and placed individually in rooting trays. Once rooted, the shoots were transplanted in pots of 7.6 cm diameter filled with the artificial substrate Pro-mix BX (Premier peat moss, Rivière-du-Loup, Quebec, Canada). Transplants were maintained in a vector-free screen house until the plants were 15 cm high. Leaves of the apical part of each plant were aseptically removed and processed for DAS-ELISA diagnosis of potato virus X (PVX), potato virus Y (PVY), potato leafroll virus (PLRV), potato virus S (PVS), Andean potato latent virus (APLV), Andean potato mottle virus (APMoV) and potato "mop-top" virus (PMTV), using CIP's Operational procedure No. 19 based on the FAO/IPGRI Technical Guidelines for the Safe Movement of Germplasm No. 19 – Potato (Jeffries, 1998). Incidence of each virus was measured as the percentage of plants with positive reaction in DAS-ELISA in relation to the total number of plants of the same genotype tested. Evaluations of viral infection were made between May and October 2010.

Screening for Late Blight in subsistence farmers' collection

Germplasm used in this study was obtained from farmers' collections from the districts Paucartambo (between 10° 45' to 10° 48 ' south latitude) and Yanacancha (between 10° 37' to 10°39' S in the department of Pasco, and the district of Ulcumayo (10° 58' to 10° 65' SL), which is in the department of Junin. An on-farm field trial was carried out between October 2013 and April 2014. The experiment was installed in a farmer's plot (3623 masl, 10°44'10.72" SL) near Paucartambo, This is a location of consistently high disease pressure and where all farming activities are based on the Chaqro farming system.

Thirteen local potato landraces (Table 2) used widely in the indigenous farming system were evaluated for resistance to *P. infestans*, the cause of potato late blight. Three Peruvian genotypes (Venturana, Serranita, and Canchan) with different levels of resistance were used as controls. Planting density was 0.9 m between rows and 0.35 m between plants. The plants were protected against *P. infestans* with a contact fungicide (Mancozeb 45%) for the first 35 days after planting, after which they were exposed to natural infection with no further fungicide applications. The experiment was carried out in a randomized complete block design with three replications (Box *et al*., 1999). The percentage of leaf area affected of each plant was evaluated weekly after 42 days of planting. A total of fourteen disease severity readings were recorded. The relative area under the disease progress curve (rAUDPC) was calculated for each genotype from ratings of foliar infection. The rAUDPC values were then used to calculate susceptibility scale values for each genotype (Yuen and Forbes, 2009) and for this purpose a scale value (SV) of 9 was assigned to Canchan, known for its high susceptibility to late blight. Analysis of variance and means comparisons procedures (Duncan's) were used to compare SV values using SAS 9.2 statistical software (SAS Institute Inc., Cary, NC).

Results

Diseases and pests affecting foliage

Late blight was the only disease or pest causing significant damage to foliage (Table 3). On average, late blight was present in 84 % of plants (range 50 - 100 %) and caused an average foliar damage of 24 % (range 4 - 40%). Early blight incidence was on average 7 % and caused little or no damage to foliage. Incidence of plants with insect damage ranged from 14 to 28% however damage to foliage was only between 1 and 3%. Given the low damage of most diseases and pests, varietal differences were only considered for late blight. Ishkupuru and Lengua de vaca had very low levels of late blight severity in this survey.

Table 3. Incidence and severity of the most important diseases and pests found on potato landraces and bred varieties in the Peruvian highlands.

Landraces or bred varieties	Plants [b]	Late blight [a]		Early blight		Andean potato weevil		Potato leaf beetle		Potato flea beetle	
		Inc. [c]	Sever. [d]	Inc. [c]	Sever. [d]	Inc. [c]	Sever. [d]	Inc. [c]	Sever. [d]	Inc. [c]	Sever. [d]
Alianza	23	86.96	31.66	8.70	1.61	13.04	1.57	21.74	1.81	30.43	3.71
Ambar	8	100.00	29.38	0.00	0.00	0.00	0.00	0.00	0.00	25.00	1.88
Blanca	87	79.31	21.92	17.24	2.04	17.24	1.45	29.89	0.69	25.29	3.80
Chata negra	43	67.44	27.02	2.33	0.83	11.63	0.87	11.63	1.55	39.53	3.52
Wayro rojo	56	80.36	23.70	14.29	1.41	10.71	1.14	19.64	1.09	21.43	3.20
Wayrush	22	95.45	34.44	0.00	0.00	13.64	1.38	13.64	0.47	50.00	4.97
Ishkupuru	8	50.00	3.50	0.00	0.00	25.00	1.25	37.50	3.13	12.50	0.01
Lengua de vaca	10	50.00	3.80	0.00	0.00	20.00	1.00	20.00	1.00	40.00	2.00
Liberteña	17	70.59	11.32	0.00	0.00	29.41	2.95	11.75	1.22	52.94	3.00
Muru Wayro	33	75.76	14.59	0.00	0.00	15.15	0.73	6.06	0.50	24.24	1.96
Negra	239	97.91	31.09	21.34	1.82	7.53	0.75	25.94	1.29	30.13	3.12
Peruanita	63	98.41	34.95	7.94	0.68	14.29	1.38	39.68	0.87	20.63	3.95
Putish	54	100.00	28.90	37.04	4.26	20.37	1.50	33.33	1.90	3.70	2.07
Juito	55	100.00	39.23	9.09	1.55	20.00	1.53	21.82	0.50	12.73	3.02
Juito Amarillo	5	100.00	23.00	0.00	0.00	0.00	0.00	0.00	0.00	40.00	6.00
Yungay	13	100.00	24.62	0.00	0.00	0.00	0.00	7.69	0.77	23.08	0.77
Average		84.51	23.94	7.37	0.88	13.63	1.09	18.77	1.04	28.23	2.93

[a] Pest names: Late blight (*Phytophthora infestans*); Early blight (*Alternaria* spp.); Andean potato weevil (*Premnotrypes* spp.); Potato leaf beetle (*Diabrotic*a spp.) and Potato flea beetle (*Epitrix* spp.).
[b] Number of plants evaluated; total = 736 plants.
[c] Incidence expressed as the percentage of plants with presence of a pest or disease.
[d] Severity expressed in percentage of foliage damaged by a particular pest or pathogen.

Systemic virus infection and tuber borne pests

The viruses X and S were found in 28.39 % and 22.13 % of the plants, respectively, and thus were the most common of viruses tested. The remaining viruses were relatively rare with APMoV, APLV, PVY, PLRV and PMTV being found in 3.82 %, 2.11 %, 1.16%, 0.35% and 0.15 % of plants, respectively (Table 4).

Table 4. Incidence of seven viruses found in potato landraces and bred varieties in the Peruvian highlands.

Variety	Plants [b]	Incidence[a]						
		PVX [c]	PVY	PLRV	PVS	APLV	APMoV	PMTV
Alianza	23	8.70	0.00	4.35	17.39	0.00	26.09	0.00
Ambar	8	0.00	0.00	0.00	12.50	0.00	12.50	0.00
Blanca	87	36.78	0.00	0.00	18.39	1.15	0.00	0.00
Chata negra	43	16.28	2.33	0.00	39.53	2.33	0.00	2.32
Wayro rojo	56	23.21	0.00	0.00	23.21	0.00	1.79	0.00
Wayrush	22	18.18	0.00	0.00	31.82	0.00	13.64	0.00
Ishkupuru	8	50.00	0.00	0.00	25.00	0.00	0.00	0.00
Lengua de vaca	10	70.00	10.00	0.00	40.00	10.00	0.00	0.00
Liberteña	17	29.41	5.88	0.00	35.29	5.88	5.88	0.00
Muru Wayro	33	21.21	0.00	0.00	15.15	0.00	0.00	0.00
Negra	239	14.23	0.42	1.26	33.89	0.42	1.26	0.00
Peruanita	63	17.46	0.00	0.00	17.46	4.76	0.00	0.00
Putish	54	40.74	0.00	0.00	24.07	3.70	0.00	0.00
Juito	55	21.82	0.00	0.00	12.73	5.45	0.00	0.00
Juito amarillo	5	40.00	0.00	0.00	0.00	0.00	0.00	0.00
Yungay	13	46.15	0.00	0.00	7.69	0.00	0.00	0.00
Average		28.39	1.16	0.35	22.13	2.11	3.82	0.15

[a]Incidence of seven viruses tested using ELISA, expressed as percentage of plants with presence of each virus percentage (%).
[b]Number of evaluated plants; total = 736 plants
[c]Virus acronyms : PVX=Potato virus X; PVY = Potato virus Y; PLRV = Potato leafroll virus; APLV = Andean potato latent virus; APMoV = Andean potato mottle virus; PMTV = potato mop – top virus.

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It is important to note that PVY and PLRV, considered the most important potato viruses worldwide, were found at a very low frequency.

The most frequently found tuber disease was black scurf caused by *Rhizoctonia solani* with an average incidence of 14.27 % and severity ranging from 1.07 to 15.00% (Table 5). The second most important problem on tubers was caused by the Andean weevil larvae (*Premnotrypes* spp), with 8.27 % average incidence and severity ranging from 1.31 to 15.03 %. Powdery scab (*Spongospora subterranea*), dry rot (*Fusarium* spp.), tuber blight (*P. infestans*), and soft rot (*Pectobacterium* spp.) had average incidences of 3.47 %, 2.92 %, 1.47 % and 1.11 %, respectively. Anthracnose caused by *Colletotrichum* spp. had an average incidence of 7.65 %. Genotypes appeared to differ in susceptibility to *Colletotrichum spp*., as Alianza, Ambar and Putish had incidences between 20 and 30%, while the other genotypes had no symptoms (Table 5).

Table 5. Incidence and severity of the most important potato diseases and pests found in tubers of potato landraces and bred varieties surveyed in the Peruvian highlands.

		Black scurf [a]		Dry rot		Powdery scab		Soft rot		Late blight		Black dot		Andean potato weevil	
Variety	**Tubers** [b]	**Inc.** [c]	**Sever.** [d]	**Inc.**	**Sever.**	**Inc.**	**Sever.**	**Inc.**	**Sever.**	**Inc.**	**Sever.**	**Inc.**	**Sever.**	**Inc.**	**Sever.**
Alianza	232	8.62	1.34	1.72	1.30	1.29	0.13	0.43	0.63	0.00	0.00	29.74	4.02	11.64	8.89
Ambar	72	33.33	3.75	1.39	1.25	0.00	0.00	0.00	0.00	0.00	0.00	27.78	6.25	6.94	4.38
Blanca	1263	14.01	2.56	2.53	2.10	2.06	1.88	0.87	1.33	2.69	1.54	0.71	0.20	14.33	6.79
Chata negra	406	4.19	1.07	3.20	1.94	2.46	1.35	3.20	0.96	3.45	1.83	8.13	1.90	6.65	15.19
Wayro rojo	384	6.25	2.16	6.25	2.14	2.60	1.56	1.56	0.56	2.34	0.95	3.65	1.08	14.58	10.17
Wayrush	206	10.68	2.50	2.43	3.07	1.94	2.50	0.00	0.00	0.49	1.25	0.00	0.00	14.08	16.00
Ishkupuru	69	20.29	4.38	1.45	1.25	5.80	1.25	4.35	2.50	0.00	0.00	0.00	0.00	1.45	0.63
Lengua de vaca	117	9.40	15.00	0.85	10.00	13.68	15.00	3.42	10.00	5.13	10.00	0.00	0.00	1.71	5.00
Liberteña	318	5.35	2.50	5.97	3.86	7.23	2.29	2.52	1.74	5.97	3.20	0.00	0.00	1.26	0.69
Muru Wayro	358	10.06	2.15	0.84	0.64	5.59	2.77	0.56	0.75	3.35	1.88	12.01	2.75	8.66	13.15
Negra	1867	18.37	3.85	1.34	1.30	4.02	1.86	0.54	0.29	0.05	0.07	14.89	2.65	7.61	6.83
Peruanita	916	24.24	4.62	0.44	0.69	0.98	0.95	0.11	0.26	0.00	0.00	3.17	0.68	15.07	8.71
Putish	512	10.55	1.84	2.73	1.72	1.56	1.10	0.20	0.18	0.00	0.00	22.07	3.34	5.86	3.67
Juito	488	22.95	4.07	1.02	0.79	3.28	1.64	0.00	0.00	0.00	0.00	0.20	0.21	14.55	5.45
Juito amarillo	49	16.33	6.00	6.12	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.08	10.00
Yungay	131	13.74	1.54	8.40	4.62	3.05	1.69	0.00	0.00	0.00	0.00	0.00	0.00	3.82	1.92
Average		14.27	3.71	2.92	2.54	3.47	2.25	1.11	1.20	1.47	1.30	7.65	1.44	8.27	7.34

[a] Pest names: Black scurf (*Rhizoctonia solani*); Dry rot (*Fusarium* spp.); Powdery scab (*Spongospora subterranea*); Soft rot (*Pectobacterium* spp.); late blight (*Phytophthora infestans)*; Black dot (*Colletotrichum* spp.) ; Andean potato weevil (*Premnotrypes* spp.).
[b] Number of tubers evaluated; total = 7,388 tubers.
[c] Incidence expressed as the percentage of plants with presence of a particular pest or disease.
[d] Severity expressed as the percentage of tuber area damaged by a particular pest or pathogen.

Screening for Late Blight in subsistence farmers' collection

Susceptibility scale values calculated for five genotypes (Milagro, Niño runtush, Rurun sasha, Cunchucano and Peruanita) were higher (between 15.85 and 10.07) than those obtained for Canchan (SV= 9.00), used as a susceptible control in the experiment (Table 2). Venturana (SV= 0.77) and Serranita (SV=1.94) had the lowest susceptibility scores but several landraces also had relatively low scores: Chaulina (SV=3.23), Chaulina Tajacaja (SV= 3.64) and Negro cayash (SV= 4.74). The other seven genotypes obtained values between 6.32 to 7.25, indicating an intermediate level of infection.

Discussion

In this study, late blight, caused by the oomycete *P. infestans*, was the main biotic constraint in potato landraces cultivated in Pasco, Peru. This disease was also recently reported as the most important in fields located between 3400 to 3900 m of altitude in the departments of Huancavelica, Huánuco, Pasco and Junín (Zuñiga and

Rojas, 2011). *P. infestans* has also been isolated in the last few years from potato landraces growing at 4225 masl in the central highlands of Peru, which is significantly higher than any isolations previously recorded in the International Potato Center's isolate database (unpublished data). These results are consistent with GIS based analyses of future climate scenarios that suggest an increase in late blight severity at higher altitudes (Giraldo *et al*., 2010).

The low severity of early blight found in landraces and bred varieties may be due to weather conditions, as early blight is favored by warmer temperatures (Agrios, 2005). However, low early blight severity may also reflect host resistance in the Andean landraces, which has been reported previously (Torres and Ames, 1995).

Similar to our results, de Haan *et al*. (2009) also found black scurf to be the most important tuber borne problem of potato landraces in Peru. Incidence of black scurf was also found to be very high in farmer's seed tubers (78%) in Ecuador (Fankhauser, 2000). Anthracnose (*Colletotrichum* spp.) was found at relatively high frequency in some genotypes, but this disease is rarely cited as a problem in the high Andes. We assume that this disease is poorly identified by many farmers because the tuber skin color dissimulates the spots caused by this pathogen.

Hofmaster (1979) mentioned that severe foliage damage caused by *Epitrix* spp. is not always associated with severe damage in the tuber, so that plants with light leaf damage may suffer severe damage to the tuber, and vice versa. This may explain why we found low damage of tubers caused by *Epitrix* spp. in spite of relatively high incidence in foliage.

Alcazar and Cisneros (1999) reported that the complex of *Premnotrypes* spp. causes severe damage to potato crops from Argentina to Venezuela at altitudes above 2800 m. Damage from Andean weevil (*P. vorax*) was also found to be high in farmer's seed of bred varieties in Ecuador (Fankhauser, 2000). Alcazar and Cisneros (1991) found significant differences between species of *Solanum* in relation to the damage caused by the adult Andean potato weevil in the foliage and of larvae in the tubers. Thus, the highly variable results we found among landraces could reflect either patchiness in the presence of the pest, host resistance or some combination of these factors.

Consistent with our results, another study carried out in Peruvian central highlands (Scurrah *et al*., 2009), found that the main viruses affecting potato landraces were PVX, PVS, APMV and APLV, whereas PVY and PLRV were found in very low frequencies. de Haan (2009) also reported low incidence of infection with PMTV, PLRV and PVY, however APMoV and PVX were found to have relatively high overall infection incidences of 18.1% and 47%, respectively. That report was based on serological tests done on 1317 samples of potato landraces from different Peruvian highland communities.

Contrary results were reported by Bertschinger (1992) who found that the incidence of PLRV and PVY was significantly higher than PVX and PVS in potato landraces than in bred cultivars (Bertschinger *et al*., 1990). In the latter case, the potato landraces may have been planted at elevations below 3000 m where vector populations were higher.

Global warming has facilitated the development and dissemination of some insects such as whiteflies (Morales *et al*., 2006) and *Phthorimaea operculella* (Kroschel *et al*., 2013). Similarly, climate change in highland areas such as the Andes will lead to increased activity of aphid virus vectors. Consistent with this trend, one study carried out above 4000 masl, demonstrated that the aphids *Myzus persicae* Sulz. and *Lipaphis erysimi*

(Kaltenbach) were transmitting APLV from Maca (*Lepidium peruvianum*) to potato with an incidence of 1 to 3 % (Chuquillanqui *et al*. 2004).

In our study, the potato landraces known as Ishkupuru, Lengua de vaca, Chaulina, Chaulina Tajacaja and Negro cayash had very low LB severity and may be potential sources of resistance to that disease either directly as landrace varieties or as parents in crosses. Consistent with our results, (Perez *et al*., 2014) found that nineteen accessions of potato landraces from the CIP germplasm collection had LB resistance levels better than or similar to the resistant variety used as a control. Other studies have reported high levels of resistance to late blight in potato landraces in Peru (Gastelo *et al*., 2010), Bolivia (Plata *et al*., 2000), and Ecuador (Cañizares and Forbes, 1995).

The vary low incidence of plants containing the major yield-reducing viruses that we found and reported elsewhere (Scurrah *et al*., 2009) would indicate that simple positive selection may maintain seed health levels indefinitely in these highland landraces, although as noted above, increasing temperatures may increase disease pressure. Nonetheless, studies have shown that most farmers do not take tuber health into consideration when selecting tubers for the next cropping season (Gamboa, 1993). Furthermore, it would appear that virus infection is often not recognized by farmers and in an extreme case, some Andean farmers believe that plants showing yellowing symptoms, like that caused by potato yellow vein virus (PYVV), foretell a good harvest (Salazar, 1995). These observations highlight the already-recognized need to include capacity to identify virus symptoms in the training for positive selection (Gildemacher *et al*., 2011).

Conclusion

Due to climate change, and particularly global warming phenomenon, some high-altitude Andean communities have recently reported losses caused by diseases and pests, such as late blight and Andean Potato Weevil, which were generally considered minor problems in the past. Our study confirmed these facts are consistent with this change, but at the same time we have identified potato landraces with resistance to late blight under these conditions. Thus, one recommendation would seem to be researchers continue evaluating native landraces for late blight resistance, but in the immediate future, extension workers could use our results to recommend landraces for those areas where the disease is most severe.

Although the most yield-limiting viruses were not found in high frequency in our study, this could easily change with increasing temperatures. The majority of potato landraces only can be propagated with seed from own farmers' plots, however, is possible to reduce viral infection and increase the yields using simple techniques as positive or negative selection, for which farmers must be instructed . All these activities needs to enhance farmer capacity for integrated management and promote the use of seed quality, these issues must and should be considered by ONGs non-governmental and governmental organizations and national programs in their training and interventions activities.

Conflicts of interest

This research was realized in the International Potato Center and no conflicts of interest.

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