Effect of Viruses UMV, UVC, PapMV-U, and PLRV on Ulluco Production and Their Control

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Eight viruses infect ulluco (*Ullucus tuberosus* Caldus), an Andean tuber crop. Three of them, potato leafroll virus (PLRV), Andean potato latent virus, and potato virus T, also infect potato (*Solanum tuberosum* L.). Arracacha virus A and papaya mosaic virus, ulluco isolate (PapMV-U) infect other crops. PLRV, one of the most damaging potato viruses, was detected in healthy potato plants growing in the field next to PLRV-infected ulluco plants, indicating that viruses can be disseminated among different Andean tuber crops under natural conditions. The viruses with the highest incidence were PapMV-U and three others, ullucus virus C, ullucus mild mottle virus, and ullucus mosaic virus. In two field experiments in Junín, Peru, ulluco plants of accession MH-290 infected with ullucus virus C or ullucus mosaic virus, and ulluco plants of native variety Jaspeado infected with PLRV or PapMV-U yielded about 30% less than the healthy control plants. Also, during field exposures, only a low percentage of healthy plants were reinfected with viruses. These results indicate that the production and use of virus-free ulluco seed tubers is justified in this environment and, therefore, the use of better seed by farmers has been promoted, particularly in the La Libertad community in Junín, Huancayo Department.

Ulluco follows potato as the second most cultivated tuber in the Andean region, and as a popular food for more than 1000 years (Hodge, 1951). It is planted as a monocrop or in association with other Andean tubers such as potato, oca (*Oxalis tuberosa*), and mashua (*Tropaeolum tuberosum*) (Tapia, 1992). Both potato and ulluco are economically important for farmers. The main ulluco-producing area in Peru is Junín Department (3500 to 3800 m), located in the central Peruvian highlands (OIA, 2001). Ulluco is the crop with the highest commercial value in the La Libertad community in Junín.

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Four viruses, ullucus virus C (UVC), ullucus mild mottle virus (UMMV), ullucus mosaic virus (UMV), and papaya mosaic virus, ulluco isolate (PapMV-U), were detected before 1993 in ulluco plants from Peru and Bolivia (Brunt et al., 1982). Toledo et al. (1994) also reported the same viruses infecting in vitro ulluco accessions of Peru and Ecuador from the germplasm of the Universidad Nacional Mayor de San Marcos (UNMSM), Lima, Peru. Viruses are the main cause of degeneration (yield reduction) of vegetatively propagated crops such as potato (Salazar, 1996). Virus control is based on two principal measures: genetic resistance and the use of healthy (virus-free) seed (Salazar, 1996). Farmers produce their own ulluco seed

tubers, generation by generation, thus permitting the accumulation of viruses and degeneration of the crop. Because no work on genetic resistance has been done in ulluco, the production of better seed is the measure most likely to control viruses and increase productivity at the farm level. Understanding the viruses, e.g., their detection and importance, is the first step in producing better seed.

This paper presents an overview of the relevant research done in ulluco since 1993. Identifying the viruses in ulluco, developing reliable detection methods, and eliminating viruses using thermotherapy and meristem-tip culture were accomplished first. This research was followed by determining which viruses are important in Peru based on their distribution, incidence, and effect on yield. After this was accomplished, the use of better seed by farmers was promoted, with emphasis in the La Libertad community. Implications of these results on the epidemiology of potato viruses infecting Andean tuber crops are also discussed. Parts of this work have been published elsewhere (Lizárraga et al., 1997; Lizárraga et al., 1999; Villavicencio, 1999).

Materials and Methods

Virus identification

Accessions from CIP's in vitro collection held in trust, and plants from farmers' fields in Peru (see Table 1) were evaluated for virus infection by double antibody sandwich, enzyme-linked immunosorbent assay (DAS-ELISA). Antibodies to detect PVT were supplied by the Scottish Agricultural Science Agency. For PLRV detection, a commercial conjugated enzyme (IgG-AP) (BIOREBA, Longmont, CO, USA) was used. Rothamstead Experimental Station initially supplied antiserum to AVA. Antibodies for other viruses were prepared at CIP.

The viruses used as positive controls were isolated from ulluco accessions and maintained in plant species as indicated in Table 2.

Virus eradication and production of healthy planting materials

Ulluco line Jaspeado was cleaned up through thermotherapy (40° C and 25° C, for 6 h each, two cycles/d for 25 days) and meristem-tip culture (on 4.6 g MS basic salt medium (Murashige and Skoog, 1962) containing 2% sucrose, 2 ppm calcium pantothenate, 0.5 ppm gibberellic acid, and 0.7% agar, pH 5.6). Virus elimination was confirmed by both DAS-ELISA and sap inoculation to indicator plants. For micropropagation, plantlets were maintained between 18 and 20° C, 2000 lx intensity and illuminated for 16 h/day. Six months later, cleaned up plantlets (classified as virus-free) were established in a sterilized substrate in an insect-proof screenhouse before transplanting in the field. Certified seed (third generation) for promotion and distribution to farmers was produced from basic seed (second generation); both were field-grown.

Reinfection of virus-free ulluco plants

Jaspeado virus-free seed tubers were given to three farmers in La Libertad in 1996, and their fields were tested for virus reinfection for three growing seasons. Leaf samples from 80 plants/field selected at random were collected and evaluated by DAS-ELISA. Plants and tubers belonging to different seed categories from seed-producing fields in La Libertad during the 1997/1998 and 1999/2000 growing seasons were also evaluated.

To evaluate transmission of PLRV under natural conditions during the 1999/2000 growing season, tubers of healthy potato varieties Canchán, Revolución, and Perricholi (20 plants/cultivar) were planted next to ulluco Jaspeado infected with PLRV in La Libertad. Foliage and tubers from potato and ulluco plants were tested for virus infection by DAS-ELISA.

Table 1. Incidence of ulluco viruses in accessions from different countries and from departments of Peru maintained at CIP's in vitro germplasm collection and in plants from farmers´ fields (Junín and Huancavelica, Peru).

Samples from:	Country Department	Accessions (No.)	Infected (%)[1]							
			UVC	UMV	PapMV-U	UMMV	PLRV	APLV	PVT	AVA
In vitro collection	Argentina	39	76	45	90	66	59	21	9	0
	Bolivia	77	66	46	62	22	52	22	16	0
	Colombia	4	90	30	60	90	90	90	0	0
	Ecuador	5	39	26	50	90	0	26	0	0
	Peru	258	74	61	65	39	29	35	15	4
	Apurimac	4	30	0	60	90	0	30	0	0
	Amazonas	3	35	35	0	0	0	0	0	0
	Ancash	25	90	66	66	39	31	27	0	12
	Ayacucho	8	60	38	45	0	0	21	21	0
	Cajamarca	63	76	61	68	33	16	30	0	0
	Cerro de Pasco	2	0	0	0	0	45	0	0	0
	Cusco	93	82	65	73	36	41	43	13	0
	Huanuco	2	90	0	90	0	0	0	0	0
	Junín	1	0	0	0	0	0	0	0	0
	La Libertad	6	65	45	0	45	0	35	0	0
	Lima	7	68	57	32	0	22	32	0	0
	Piura	6	90	90	90	90	0	35	0	0
	Puno	38	77	74	74	61	25	33	33	0
	Total	**383**								
	(%)		**72**	**57**	**65**	**40**	**37**	**31**	**14**	**3**
Field[2]	Peru									
	Junin									
	Chicche	180	72	51	42	68	9	21	nt[3]	0
	S. Juan de Jarpa	180	65	49	43	62	0	24	nt	0
	Huaracayo	180	62	51	41	56	0	17	nt	0
	Huancavelica									
	Pazos	180	72	57	43	58	0	24	nt	0
	Total	**720**								
	(%)		**67**	**52**	**42**	**61**	**4**	**22**		**0**

Note: See Table 2 for full names of viruses.

[1] The arcsin √percentage transformation (Steel and Torrie, 1980).

[2] Data from Villavicencio, 1999.

[3] nt = not tested.

Effect of viruses on ulluco production

Cropping season 1995/96. Tubers of accession MH-290 infected by viruses UMV, UVC, PapMV-U, and UMV+UVC+PapMV-U were planted in a randomized block design with five treatments (including a healthy control) and four replications of 132 plants/plot in Huancayo, Junín (3280 m). Carlos Arbizu (CIP) provided the virus-free MH-290 accession (from Bolivia).

Cropping season 1998/99. Tubers of variety Jaspeado infected by viruses UMV, UVC, PapMV, and PLRV were planted in La Libertad (3500 m), following the same experimental design as before, but with 40 plants/plot.

In both cases, foliage growth (height) of plants was measured 5 months after planting. Only the inner rows were harvested and the yield recorded. Auto-infection (percentage of virus-infected

Table 2. List of viruses infecting ulluco.

Genus	Virus	Virus isolated from accession (origin)/ Institution[1]	Virus maintained in[2]	Infecting other crops
Comovirus	UVC (Ulluco Virus C)	UH 009 (UNMSM)/ Huancayo - Junín	*Chenopodium quinoa* Willd.	-
Potyvirus	UMV (Ulluco Mosaic Virus)	UH 009 (UNMSM)/ Huancayo - Junín	*Nicotiana benthamiana* Domin.	-
Potexvirus	PapMV-U (Papaya Mosaic Virus, ulluco isolated)	UH-009 (UNMSM)/ Huancayo - Junín	*C. murale* L.	Oca, mashua
Tobamovirus	UMMV[3] (Ullucus Mild Mottle Virus)	U-016-83 (CIP)/Cerro de Pasco	*N. clevelandii* Gray x *N. bigelovii (tarr) S. Wats.*	-
Luteovirus	PLRV (Potato Leafroll Virus)	MH-290 (CIP)/ Huancayo - Junín[4]	*Ullucus tuberosus* (MH-290)	Potato
Tymovirus	APLV[3] (Andean Potato Latent Virus)	UP-271 (UNMSM)/ Puno	*N. clevelandii* x N. *bigelovii*	Potato
Trichovirus	PVT[3] (Potato Virus T)	MH-463 (CIP)/Cusco	*C. quinoa*	Potato, oca, mashua
Nepovirus	AVA[3] (Arracacha Virus A)	UP-254 (UNMSM)/ Puno	*C. quinoa*	Arracacha

[1] Germplasm collection from UNMSM (Universidad Nacional Mayor de San Marcos, Lima, Peru) and CIP (International Potato Center, Lima, Peru).

[2] All virus isolates, except PLRV, were mechanically transmitted.

[3] Virus transmitted by true seed reported in other hosts, but not yet confirmed in ulluco.

[4] PLRV was isolated from the naturally infected accession and maintained in the same plant.

progeny tubers from a virus-infected plant) was determined by DAS-ELISA testing of sprouts on 10 tubers/plant from selected plants of each treatment. Data were analyzed using MSTAT or SAS software (SAS 1989).

To compare the behavior of Jaspeado basic seed with infected seed, tubers were planted in a randomized block design with four treatments (basic, infected, from positive selection, and from farmer) and with four replications of 40 plant each in La Libertad during the 1997/98 growing season. This experiment was repeated at the same site during the 1998/99 growing season, except that the treatments were virus-free tubers, certified seed, and infected tubers (one tuber of 25 g or five, 5-g tubers planted together).

Results

Virus identification and viral incidence

Eight viruses infect ulluco (Table 2). Of these, viruses PLRV, APLV, PVT, and AVA were found infecting the crop during these studies.

Over 90% of the plants evaluated, both from the in vitro collection and farmers´ fields, were infected with viruses. Complex infections (two or more viruses) were common. Viruses with the highest incidence and distribution were UVC, UMV, PapMV-U, and UMMV (Table 1). Only

Figure 1. Ulluco plant infected with complex of viruses, showing mosaic and growth reduction (right).

plants severely affected by complexes of viruses showed evident symptoms in the field (Figure 1).

Virus eradication and reinfection of virus-free ulluco plants

Thermotherapy, alternating between 40° C and 25° C in two cycles daily, eliminated viruses from meristems in Jaspeado plants infected with up to three viruses. UMMV and PapMV-U were the most difficult to eliminate. The varieties Canario, Tarmeña, and Picado de Pulga were cleaned of viruses following the same procedure. Thermotherapy with a continuous temperature of 38–40° C is less efficient because ulluco plants become extremely stressed, causing elevated plant mortality.

The reinfection rate of virus-free ulluco was low in farmers' fields until the third field exposure, when PLRV infection was over 50% (Table 3). Ulluco plants from basic seed (two field exposures) and certified seed (three field exposures), analyzed during the 1997/98 cropping season, were approximately 40% infected with PLRV. But PLRV was not detected in certified seed tubers tested in 1999 (Table 4). Most were infected with APLV, UMV, UVC, and UMMV (Table 4).

PLRV was detected by DAS-ELISA in some of the healthy potato plants growing next to PLRV-infected ulluco (two plants each of potato cultivars Canchán and Revolución), as well as in healthy ulluco plants (5 of 20 control plants). However, sprouts of the harvested potato tubers tested negative for PLRV.

Table 3. Reinfection (%)[1] of virus-free ulluco Jaspeado plants in farmers' fields in La Libertad, Junín, Peru (3500 m).

Field	Planting season					
	1996-1997		1997-1998		1998-1999[2]	
Farmer 1	PLRV	1.3 ± 2.5	Not planted		Not planted	
	APLV	1.3 ± 2.5				
Farmer 2	UMV	1.3 ± 2.5	UMV	5 ± 4.8	UMV	27.5 ± 9.8
	UVC	1.3 ± 2.5	UVC	2.5 ± 3.5	UVC	12.5 ± 7.2
			PapMV-U	1.3 ± 2.5	PapMV-U	5.0 ± 4.8
			UMMV	2.5 ± 3.5	UMMV	13.8 ± 7.6
	PLRV	10.0 ± 6.6	PLRV	11 ± 7.0	PLRV	51.3 ± 11.0
			APLV	2.5 ± 3.5	APLV	13.8 ± 7.6
Farmer 3	PLRV	2.5 ± 3.5	Not planted		Not planted	

Note: See Table 2 for full names of viruses.

[1] ± confidence limits (p = 0.05).

[2] Plants were evaluated for all ulluco viruses, but only those detected are indicated in the table.

Table 4. Reinfection (%)[1] of Jaspeado ulluco plants and seed tubers from virus-free ulluco produced in field in La Libertad, Junín, Peru (3500 m).

Samples[2]	Category[3]	Evaluated	UVC	UMV	PapMV-U	UMMV	PLRV	APLV	PVT	AVA
Plants	Virus-free	48	0	0	0	0	0	0	nt[4]	0
	Basic	105	4±3.7	4±3.7	0	4±3.7	41±9.5	11±6.0	nt	0
	Certified	58	12±8.5	12±8.5	3±4.5	9±7.5	48±13.1	28±11.8	nt	0
Tubers	Certified	49	33±13.4	45±14.2	0	27±12.7	0	57±14.1	0	0

Note: See Table 2 for full names of viruses.

[1] ± confidence limits (p = 0.05).

[2] Plants and tubers from cropping season 1997-1998 and 1999-2000, respectively.

[3] Virus-free = 1st generation in screenhouse; Basic = 2nd generation in field; Certified = 3rd generation in field.

[4] nt = not tested.

Effect of viruses on ulluco production

The only symptoms associated with virus infection observed during both cropping seasons was a temporal mosaic in ulluco plants infected with UMV and PapMV-U. Viruses UMV or UVC significantly reduced yield of MH-290; as did PLRV and PapMV-U on Jaspeado plants, (Table 4 and Figure 2). Growth (height) was also significantly different in MH-290, but not in Jaspeado (data not shown). Autoinfection was close to 100% for UMV, UVC, and PapMV-U in accession MH-290, but was lower (88% for UMV, 22% for UVC, and 20% for PLRV) in Jaspeado (data not shown).

Plants from infected seed—either naturally or artificially—from field experiments, farmers, or positive selection from apparently healthy plants yielded fewer commercial-quality tubers than those from virus-free, basic, or certified seed (Tables 5 and 6), although the differences were not always statistically significant. The productivity of plants from seed tubers of different sizes (five tubers of 5 g vs 1 tuber of 25 g) was similar (Table 6).

A total of 1140 kg of high quality Jaspeado seed tubers were distributed among 12 farmers from Pazos, Chicche, La Esperanza, and La Libertad during 1996-1999. Over 80% of the farmers who received promotional seed showed interest in cultivating and propagating it to increase their income. Some farmers even planted commercial fields (averaging around I.0 ha). Data is being collected to evaluate the benefit.

Discussion

Our observations and those from Toledo et al. (1994) indicate that viruses UVC, PapMV-U, UMV, and UMMV are widespread in ulluco (Table 1). High viral incidence has also been reported in Bolivia and Ecuador (Duque and Hermann, 1994; Badani et al., 1997). Eight viruses have been found infecting ulluco. Viral incidence data of PLRV, APLV, PVT, and AVA were not available before this study. The information compiled here on the identification and distribution of viruses in ulluco permits recognizing disseminating viruses and those restricted to certain geographical areas (Table 1). It is of epidemiological interest that PLRV, APLV, PVT, and AVA naturally infect other Andean crops, especially potato (Table 2) (Jones and Kenten, 1978; Lizárraga et al., 1997; Lizárraga et al., 2000). Farmers' traditional cropping systems (ulluco and potato in mixed cropping, ulluco fields beside potato fields, or ulluco planted in fields where potato was previously grown) favor virus dissemination between crops. That could be occurring with PLRV, one of the most damaging potato viruses, and this study suggests that, in Peru, potato seed-producing fields should be far from both potato and ulluco fields. Under experimental conditions, PLRV was transmitted by the green peach aphid (*Myzus persicae*)

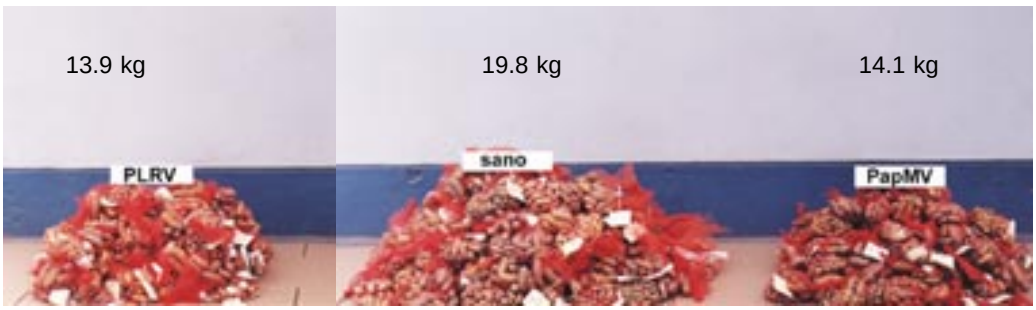

Figure 2. Effect of viruses on yield of ulluco Jaspeado in secondary infection with PLRV and PapMV-U. Tubers harvested from 20 plants per each treatment.

Table 5. Average yield of tubers (kg) from ulluco plants (MH-290 and Jaspeado) with secondary infection (seed tubers were virus infected), planted in two different cropping seasons and places in Junín, Peru.

Cropping season, place and variety	Treatment	Yield[1]		Yield reduction (%)[2]
		Total weight	Commercial quality	
1995-1996	Healthy control	26.9 a	16.0 a	
(Huancayo)	UMV	19.1 bc	10.5 bc	29
MH-290	UVC	19.7 bc	10.7 bc	27
	PapMV-U	24.2 a	14.5 ab	10
	UMV + UVC + PapMV-U	16.7 bc	10.5 bc	38
1998-1999	Healthy control	19.8 a	nt [3]	
(La Libertad)	UMV	16.4 a	nt	17
Jaspeado	UVC	19.5 a	nt	2
	PapMV-U	14.1 b	nt	29
	PLRV	13.9 b	nt	30

Note: See Table 2 for full names of viruses.

[1] Means within columns followed by the same letter do not differ significantly (p = 0.05). Inner rows of 66 and 20 plants for MH-290 and Jaspeado, respectively.

[2] Compared with total yield of healthy control.

[3] nt = not tested.

Table 6. Average yield of tubers (kg) from ulluco Jaspeado, planted in La Libertad, Junín, (cropping seasons 1997-98 and 1998-99).

Cropping season	Treatment	Yield[1]		Yield reduction (%)[2]
		Total weight	Commercial quality	
1997-98	Basic	18.90 a	13.19 a	
	Infected[3]	14.11 ab	10.27 ab	22
	From farmer	13.35 b	9.39 b	29
	Positive selection	9.86 b	7.86 b	40
1998-99	Virus-free (5 g)	37.27 a	28.96 a	
	Virus-free (25 g)	36.79 a	25.09 ab	13
	Certified (5 g)	35.66 a	19.62 c	32
	Certified (25 g)	34.09 a	20.95 bc	28
	Infected (5 g)	36.80 a	19.52 c	33
	Infected (25 g)	31.98 a	18.74 c	35

[1] Means within columns followed by the same letter do not differ significantly (p = 0.05). Plot of 40 plants.

[2] Compared with commercial quality yield of healthy control.

[3] Infected with at least one of following viruses: UMV, UVC, PapMV-U, and UMMV.

from ulluco to potato and vice versa (Lizárraga et al, 1997). A similar situation might also occur with APLV in potato, and with PapMV-U, AVA, and PVT in other Andean crops. Until virus dissemination under these conditions is better understood, precautions should be taken when the germplasm collection of several Andean crops are planted in the same field.

The field experiment carried out at two sites with two genotypes showed that viruses can cause significant yield reduction in ulluco when infected seed tubers are used (secondary viral infection) (Table 5). In both experiments, no yield reduction occurred when plants were artificially infected (primary infection) during their growing period (data not shown). In other experiments with one of the genotypes, plants from virus-free tubers also yielded more than those from infected seed, and plants from basic seed (one field multiplication) yielded more than plants from seed tubers from farmers or positive selection (Table 6). During the field experiments, ulluco plants infected with only one virus

did not show symptoms and were more vigorous than those from farmers' fields nearby that were heavily infected by virus complexes. This demonstrates the risk of using seed from positive selection.

Virus control in ulluco can be achieved by eradication, and by using thermotherapy and meristem-tip culture to regenerate healthy plants. Stone (1982) used a combination of chemotherapy and meristem-tip culture to eradicate four viruses (UMV, UVC, PapMV-U, and UMMV). The eradication of viruses from ulluco using thermotherapy is more difficult than from potato, because ulluco does not tolerate high temperatures (40–42° C) for long periods. In general, potyviruses are more readily eliminated from their hosts by meristem-tip culture than potexviruses and tobamoviruses in some hosts (Stone, 1982). That could explain why PapMV-U and UMMV were the most difficult to eliminate from infected plants.

UMV and potato viruses PLRV and APLV were most frequently found reinfecting virus-free ulluco plants in La Libertad (Tables 3 and 4). PLRV and UMV are both aphid transmitted. This result is contrary to that obtained in studies of reinfection of virus-free potato plants in a nearby location, where infection by aphid-transmitted viruses (PLRV and PVY) was low (Bertschinger, 1992). Although PLRV was detected in virus-free potato plants growing next to PLRV-infected ulluco, the virus was not detected in the tubers. It is possible that PLRV infects potato plants late in the growing season and the virus moves slowly from plant to tubers. Or PLRV from ulluco may be a different strain requiring a longer time to translocate to tubers as it is adapting to the host. Lizárraga et al. (1996) observed that ulluco becomes infected by PLRV four months after graft-inoculation and that the virus has an irregular distribution in the ulluco plant. The differences in the autoinfection of accession MH-290 and Jaspeado could be due to host-pathogen-environment interactions. For example, MH-290 is from Bolivia, Jaspeado is adapted to Junín, the virus isolates used in the field experiments were from Junín, and the experiments took place in Junín.

Conclusions

Knowledge of the viruses infecting ulluco, reliable detection methods, and the eradication of viruses using thermotherapy and meristem-tip culture resulted in the production of healthy ulluco plants of Jaspeado, the variety preferred by Junín farmers. The main importance of this work is demonstrated by greater productivity of better quality seed provided to farmers in La Libertad, and their increasing acceptance and demand for it. This work also provides the groundwork for organizations engaged in cleaning up ulluco to produce better seed and to facilitate the potential interchange of valuable virus-free germplasm.

It has been confirmed that ulluco has a high incidence of viral infection, with frequent mixed viral infections. And it has been demonstrated that UMV, UVC, PapMV-U, and PLRV can lower yield in the ulluco crop in Peru. Finally, this research supports the premise that viruses (e.g., PLRV) infecting one plant species can eventually adapt in their ability to infect other species growing in close association for extended periods.

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