Potato Research
https://doi.org/10.1007/s11540-021-09495-z

Identification of Elite Potato Clones with Resistance to Late Blight Through Participatory Varietal Selection in Peru

Manuel Gastelo[1] · Gabriela Burgos[1] · Carolina Bastos[2] · Juan Miguel Perez[3] · Ronal Otiniano[3] · Hector Cabrera[4] · Raul Ccanto[5] · Maria Mayer de Scurrah[5] · Thomas zum Felde[1]

Received: 25 September 2020 / Accepted: 5 February 2021/Published online: 12 June 2021

Abstract
Potato is the most important crop in Peru and late blight is the main disease affecting the crop. However, new varieties that are resistant to late blight often lack other traits that farmers and consumers prefer. Using participatory varietal selection, this study seeks to identify clones with high potential to become varieties with resistance to late blight but also feature a high marketable tuber yield and other preferred agronomic traits. During 2016–2017, 36 clones previously selected for high levels of resistance to late blight from population B developed by the International Potato Center, and three varieties used as controls (INIA 302 Amarilis moderately resistant, INIA303 Canchan and Yungay susceptible to late blight), were evaluated in five Peruvian locations. At harvest, five clones were selected based on (i) evaluations made by farmers through Participatory Varietal Selection, (ii) analysis of mixed models and Best Linear Unbiased Predictors for tuber yield, (iii) low glycoalkaloid content in tubers, and (iv) good organoleptic quality. These clones were evaluated again during 2017–2018 in four locations. Resistance to late blight and good marketable tuber yields were identified as the most important criteria for the selection of a new potato variety. The clones CIP308488.92, CIP308495.227 and CIP308478.59 were selected as promising clones having resistance to late blight and tuber yield superior to the local varieties, INIA-303 Canchan, Yungay, as well as good organoleptic quality and low glycoalkaloid content. These clones can be suggested for variety release in similar agroecological environments.

Keywords Glycoalkaloids · Late blight · Organoleptic quality · Participatory varietal selection · Potato · Tuber yield

✉ Manuel Gastelo
mgastelo@cgiar.org

Extended author information available on the last page of the article

Introduction

In the Andes Mountains of Peru, potato is the most important crop with a cultivated area of 330,862 hectares in 2018 and an average yield of 14.9 t ha^{-1} (Ministerio de Agricultura y Riego del Peru 2018). Potato is the main source of food and income for small producers in the Andean region and is one of the main components of the regional food basket (Egusquiza 2000). The most consumed varieties in Peru—INIA-303 Canchan, Yungay and Unica—occupy more than 70% of the planted area but are susceptible to late blight (LB) disease, which is increasing its prevalence as a consequence of climate change (Litschmann et al. 2018). The International Potato Center (CIP) has developed a population of improved potato clones with high levels of resistance to this disease, high yields of tubers and other agronomic characteristics and high potential for release as varieties (population B3C3) (Landeo et al. 2001, 2008; https://data.cipotato.org/dataset.xhtml?persistentId=doi%3A10.21223%2FZOKTTA). These varieties can flourish under agroecological environments brought about by climate change.

Conventional selection of new varieties is based on agronomic characteristics such as high yields, resistance to pests and diseases and maturation rates (earliness), as well as being necessary to integrate other key preferences of actors in the potato value chain, such as consumers and wholesalers who have specific needs regarding taste, colour, price and cooking type (Cuesta and Andrade 2001; Gabriel et al. 2002; Pradel et al. 2017). Thus, the adoption rate of improved, high-yielding and disease-tolerant potato varieties will be higher by also integrating it into a seed production system (Labarta 2015).

To assure fast dissemination and adoption of improved varieties after their release, it is necessary to apply appropriate methodologies for selection. Participatory varietal selection (PVS) is one of the methodologies that might help the adoption of new varieties, as we try to show in this work. It incorporates all the actors in the potato value chain and includes special considerations of preferences by gender, as men and women often prioritise different criteria for selecting a new potato variety (De Haan et al. 2017), and these must be incorporated into breeding programs.

Participatory research integrates different stakeholder perspectives during the research process. In the case of selecting new potato varieties, researchers actively solicit input from farmer and consumer groups differentiated by gender to ensure that the varieties selected will meet the demands of local stakeholders by including traits that local farmers prioritise but researchers might overlook (Badstue et al. 2012). Decentralised, locally-responsive breeding and PVS enable the development and testing of candidate varieties under farm conditions. Moreover, these approaches can reduce timeframes for uptake by increasing the likelihood of acceptance through early exposure of farmers and consumers (men and women) to new materials, by involving them in the selection process (Klawitter et al. 2009) and by anticipating the need for adequate quantities of seed at the time of variety release. Participatory plant breeding methods show great promise in the development of new varieties that meet the technological needs of end users, mainly poor farmers who are not well integrated into market economies (Morris and Bellon 2004).

At CIP in Peru, we have three successful examples of potato variety selection using PVS. In the Altiplano region, PVS led to the selection of the variety INIA-317

Altiplano for its resistance to the Andean weevil, tolerance to frost and drought, high yield, early maturity and high content of dry matter (Arcos et al. 2015). In Huancavelica, Junin and Huanuco, stakeholders identified resistance to LB, abundant foliage, tolerance to drought, and high yield, uniform size and tuber health at harvest as selection criteria for a new potato variety. The selected clones in these localities CIP396034.268, CIP393079.4 and CIP387096.2 have higher resistance to LB compared to the INIA-303 Canchan and Unica varieties which are susceptible to this disease (Zuñiga et al. 2018). In the community of Lircay in Huancavelica, stakeholders chose the variety INIA-321 Kawsay for its flowering and vigorous plants; they associate this trait with plants more resistant to LB and for its good yield and large tubers at harvest (Janampa 2012). The preferences of medium and large farmers are highly related to market preferences, but for small farmers they are related to quality for their own consumption, and resistance to abiotic or abiotic factors that allow them to obtain yields under their crop management conditions.

There are many illustrative examples of successful PVS around the world. In Bhutan, a farmer preference study found that farmers prefer varieties with red skin tubers (Bajgai et al. 2018). In Ethiopia, breeders developed new potato varieties with resistance to LB and to be sown in rainy seasons, but the farmers did not adopt them. Afterward, breeders used PVS and found high priority for six characteristics (drought tolerance, LB resistance, high yield, long shelf life, suitability for boiling and suitability for stew) that had been overlooked in the conventional potato breeding program (Tesfaye 2013; Abebe et al. 2013; Mudege et al. 2015; Semagn et al. 2015, 2017). In Syria, researchers found that farmers from marginal environments do not adopt higher yielding varieties if they have not participated in the development process (Southeast Asia Regional Initiatives for Community Empowerment 2007).

Climate change also affects the quality of the tubers. As temperatures and irregular rainfalls increase, the glycoalkaloid content is in risk of increase. High levels of glycoalkaloids can produce a bitter taste and can be unsafe for human consumption at levels exceeding 20 mg per 100 g fresh weight of potatoes (Storey and Davies 1992; Ruprich et al. 2009). Hence, it is important to monitor the glycoalkaloid levels of tubers and evaluate the quality of tubers for consumption through organoleptic tests. These tests are included in the PVS methodology.

The main objective of this study was to use PVS to select LB-resistant clones with high potential to become varieties with high marketable tuber yields and other preferred agronomic traits. Successful application of PVS will enable greater adoption and dissemination of these varieties, ensuring their profitability, food safety, and improving the living conditions of small farmers.

Materials and Methods

PVS Evaluation 2016–2017

Thirty-six advanced potato clones from CIP's B3C3 population, belonging to the third cycle of recurrent phenotypic selection of the B3 population, derived from crossing the species *Solanum tuberosum* spp. *andigena* and *tuberosum*, *S. demissum*, *S. bulbocastanum*, *S. acaule* and *S. phureja*, were evaluated in Cajamarca, La Libertad and Huancavelica in Peru, using the PVS approach (De Haan et al. 2017). These clones have high levels of resistance to LB, high tuber yield and some clones displayed tolerance to heat, resistance to Potato Virus X (PVX), Potato Virus Y (PVY), good organoleptic quality and adaptation to mid-elevation and highlands. The clones were planted in two experiments of 18 clones each during 2016–2017. Two local susceptible varieties (INIA-303 Canchan, INIA-302 Amarilis and/or Yungay) were used as controls (Table 1).

Experiment 1 was planted in Chaquil, Cajamarca; in Canaypata, Huancavelica; and in Macullida, La Libertad. Experiment 2 was planted in Chucmar, Cajamarca and in La Soledad, La Libertad (Table 2).

In the two seasons (2016–2017 and 2017–2018), the experiments were sown using statistical design of randomised complete blocks (RCB) with 4 replications of 10 plants each. The distance between rows was 1.00 m and between plants 0.30 m; the dose of fertilisation was 180-160-160 of NPK and the control of weeds and pests was carried out in a timely manner. Contact fungicides (Mancozeb) were applied before hilling to control LB, especially to protect susceptible controls. The harvest was at 120 days after planting.

PVS Evaluation 2017–2018

In 2017–2018, five selected potato clones from 2016–2017 were evaluated using PVS. These clones were selected based on preferences of farmers through PVS, high tuber yield, low glycoalkaloid content and good organoleptic quality (flavour) (Table 3).

The experiment included the five clones and two local varieties as controls (INIA-303 Canchan, Yungay and/or INIA-302 Amarilis) and was planted in four locations: Chucmar in Cajamarca, La Aurorita and Arcopampa in La Libertad, and Cañaypata in Huancavelica (Table 2). Using RCB with four replications of 20 plants each, we employed PVS at flowering and harvest phenological phases of potato crop. In each phase, the selection criteria for a new variety were identified and prioritised and the clones were ranked, taking into account preferences by gender. To mark their preferences, each male farmer received six seeds of corn, whilst women were given six seeds of fava beans. Farmers proceeded to select three criteria and three clones of their preference, using three seeds for those they ranked first, two seeds for second and one seed for third. At the harvest, an organoleptic test of the clones was carried out to determine their appearance, flavour and texture using a panel of ten evaluators (five men and five women). Harvest took place 120 days after planting. The numbers and weights of marketable and non-marketable tubers per plot were recorded and the marketable and total yields per hectare were calculated.

Total Glycoalkaloid Analysis

At harvest, 15 tubers of each sample were collected and brought to the Quality and Nutrition Laboratory in CIP-Lima, Peru, for sample preparation and glycoalkaloid analysis. Freeze-dried and milled samples of each tuber were prepared and stored at − 20 °C until analysis. Total glycoalkaloid analysis was performed using the method described by Burgos et al. (2014) in which glycoalkaloid extraction was executed using methanol and chloroform before concentration at 60 °C in a rotary evaporator. The

Table 1 B3C3 potato clones with resistance to LB

#	Clone	Female	Male	SC	FC	TS	ED	Resistance			HT	Chip colour	Number exp.
								LB	PVX	PVY			
1	CIP308427.194	CIP395017.229	CIP395011.2	Pi	Cr	Ob	S	R					1
2	CIP308431.273	CIP395096.2	CIP395011.2	Cr/Pi	Cr	El	S	R	ER				1
3	CIP308433.101	CIP395109.29	CIP395011.2	Cr/Pi	CR	OV	S	R	ER	ER	T	2	1
4	CIP308433.160	CIP395109.29	CIP395011.2	Rd	Cr	Ov	S	R	ER			2	1
5	CIP308433.351	CIP395109.29	CIP395011.2	Cr	Cr	El	S	R					1
6	CIP308436.173	CIP395111.13	CIP395011.2	Cr	Cr	El	S	R					1
7	CIP308436.245	CIP395111.13	CIP395011.2	Cr	Cr	Ov	S	R				2	1
8	CIP308436.84	CIP395111.13	CIP395011.2	Rd	Cr	Ov	S	R					1
9	CIP308441.227	CIP395114.5	CIP395011.2	Cr/Pi	Cr	El	S	R			T	2	1
10	CIP308447.74	CIP396004.337	CIP395011.2	Rd	Cr	Ob	S	R					1
11	CIP308476.16	CIP395077.12	CIP395011.2	Rd	Cr	Ov	S	R	ER	ER			1
12	CIP308478.123	CIP395096.2	CIP396264.14	Cr/Pi	Cr	Ob	S	R	ER			1	1
13	CIP308478.59	CIP395096.2	CIP396264.14	Cr	Cr	Ov	S	R					1
14	CIP308480.292	CIP395109.29	CIP395017.242	Cr	Cr	El	S	R	ER			2	1
15	CIP308480.298	CIP395109.29	CIP395017.242	Cr	Cr	Ov	S	R					1
16	CIP308481.314	CIP395109.34	CIP395017.229	Cr/Pi	Cr	Ov	S	R					1
17	CIP308486.187	CIP395112.32	CIP396012.288	Cr	Cr	Ov	S	R			T	2	1
18	CIP308486.221	CIP395112.32	CIP396012.288	Pi/Cr	Cr	Ob	S	R				2	1
19	CIP308486.314	CIP395112.32	CIP396012.288	Pr	Cr	Ov	S	R	ER	ER		1	2
20	CIP308486.333	CIP395112.32	CIP396012.288	Cr	Cr	El	S	R					2
21	CIP308486.355	CIP395112.32	CIP396012.288	Pr	Cr	Ob	S	R				1	2
22	CIP308487.157	CIP395112.32	CIP396264.14	Rd	Cr	Ov	S	R				2	2

Table 1 (continued)

#	Clone	Female	Male	SC	FC	TS	ED	Resistance			HT	Chip colour	Number exp.
								LB	PVX	PVY			
23	CIP308487.390	CIP395112.32	CIP396264.14	Rd	Cr	Ov	S	R	ER	ER		2	2
24	CIP308488.198	CIP395112.36	CIP396004.337	Rd	Cr	El	S	R				2	2
25	CIP308488.92	CIP395112.36	CIP396004.337	Rd	Cr	Ov	S	R				2	2
26	CIP308492.207	CIP395114.5	CIP395096.7	Rd	Cr	Ov	S	R					2
27	CIP308495.227	CIP395179.21	CIP395017.227	Cr/Pi	Cr	Ob	S	R			T		2
28	CIP308495.237	CIP395179.21	CIP395017.227	Pi/Cr	Cr	Ov	S	R					2
29	CIP308499.143	CIP396004.263	CIP396038.107	Rd	Ye	Ov	S	R					2
30	CIP308499.76	CIP396004.263	CIP396038.107	Rd	Ye	Ov	S	R				2	2
31	CIP308502.95	CIP396008.104	CIP396012.266	Pr	Cr	El	S	ER	ER				2
32	CIP308505.377	CIP396009.239	CIP396004.337	Cr/Pi	Cr	Ov	S					1	2
33	CIP3085513.318	CIP396033.102	CIP395152.16	Pr	Cr	Ov	S					1	2
34	CIP308513.96	CIP396033.102	CIP395152.16	Cr	Ye	Ob	S						2
35	CIP308517.91	CIP396004.103	CIP396038.107	Rd	Cr	Ob	S	ER	ER			2	2
36	CIP308519.110	CIP396046.105	CIP396017.227	Cr	Ye	El	S	ER	ER			2	2

SC skin colour, *FC* flesh colour, *TS* tuber shape, *ED* eye depth, *R* resistant, *S* susceptible, *ER* extreme resistance, *HT* heat tolerant, *T* tolerant, *Cr* cream, *Rd* red, *Pi* pink, *Pr* purple, *Ov* oval, *Ob* oblong, *El* elliptic, *S* superficial, *Cr/Pi* cream with pink eyes, *1 or 2* good chip colour

Table 2 Sites for experiments in 2016–2017 and 2017–2018

Site	District	Province	Region	Altitude (masl)	Latitude	Longitude	Season	Agroecological zone
Chaquil	La Encañada	Cajamarca	Cajamarca	3100	7°6′59″S	78°21′59″W	2016–2017	Highlands, dry
Chucmar	Tacabamba	Cajamarca	Cajamarca	2800	6°23′36.48″S	78°36′40.63″W	2016–2017 2017–2018	Highlands, high rain, high relative humidity, high pressure of late blight
Macullida	Chugay	Sanchez Carrion	La Libertad	3601	7°47′16.5″S	77°47′32.8″W	2016–2017	Highlands
La Soledad	Chugay	Sanchez Carrion	La Libertad	3712	7°46′53″S	77°52′5.88″W	2016–2017	Highlands
La Aurorita	Chugay	Sanchez Carrion	La Libertad	3693	7°46′56.5″S	77°52′3.43″W	2017–2018	Highlands
Arcopampa	Chugay	Sanchez Carrion	La Libertad	3911	7°49′57.7″S	77°45′50.9″W	2017–2018	Highlands, more than 3800 masl
Cañaypata	Yauly	Huancavelica	Huancavelica	3952	12°45′13.3″S	74°48′46.7″W	2016–2017 2017–2018	Highlands, about 4000 masl, presence of frost

Table 3 Clones selected in 2016–2017 and tested in 2017–2018

#	Clone	Marketable tuber yield (t ha^{-1})			Total glycoalkaloid content (mg/100 g fresh weight)			Flavour		
		CJA	LLB	HVA	CJA	LLB	HVA	CJA	LLB	HVA
1	CIP308478.59	16.33	51.30	16.28	4.28	3.77	5.83	1	1	5
2	CIP308486.355	36.08	45.03		7.04	12.93		3	1	
3	CIP308488.198	36.21	43.57		5.25	12.72		1	1	
4	CIP308488.92	26.83	40.35		3.77	6.78		3	3	
5	CIP308495.227	27.26	53.15		2.06	14.87		3	3	

1 = intermediate, 3 = good, 5 = excellent

CJA Cajamarca, *LLB* La Libertad, *HVA* Huancavelica

extract was transferred to a 2% acetic acid solution and then purified using ammonium hydroxide at 85 °C and ultracentrifugation at 27,000 rpm. The pellet was placed in reaction with 85% orthophosphoric acid and read at 408 nm in a spectrophotometer. The determination of total glycoalkaloids was achieved against a standard curve of α-chaconine as reference. This parameter was used as a criterion to select clones that will continue to be evaluated next season. Only clones with a total glycoalkaloid concentration below the safe limit for human consumption (20 mg/100 g fresh weight) were selected.

Statistical Analysis

The information was stored in DATAVERSE, a database at CIP. Marketable tuber yield was analysed through linear mixed models using ASReml-R (Butler et al. 2017) and the e BLUP (Best Linear Unbiased Predictor) values were estimated (John 1989; Gilmour et al. 1997). Analysis of variance was performed using the software R and SAS v. 9.4, proc anova. Waller–Duncan means comparison test was used. The best clones were selected based on the PVS results, marketable tuber yield, low glycoalkaloid content and good organoleptic quality.

Results and Discussion

PVS Evaluation 2016–2017

At Flowering

The breakdown of participation by location and gender is provided in Table 4. In all sites, both men and women identified LB resistance as the most important selection criteria.

In Chaquil, both men and women also identified abundant foliage as the important criterion after LB resistance, followed by resistance to the Andean weevil and drought tolerance. This last criterion is important in Chaquil because rain has become erratic in

Table 4 Number of PVS participants in the flowering and harvest stages

People	Chaquil		Chucmar		Cañsaypata		Soledad		Macullida	
	FS	HS	FS	HS	FS	HS	FS	HS	FS	HS
Men	18	12	17	16	12	12	7	11	5	5
Women	10	16	1	12	12	13	7	12	5	5
Total	28	28	18	28	24	25	14	23	10	10

FS flowering stage, *HS* harvest stage

the region due to climate change. Men identified the same criteria but in different order of importance (Table 5). The clones CIP308436.84, CIP308481.314 and CIP308436.173 were selected by men and women but with different order in the ranking of preference, and the clone CIP308478.59 was selected only by men (Table 6).

Table 5 Main selection criteria, at flowering and harvest stages, identified in PVS trials 2016–2017

Selection criteria	Stage	Chaquil		Chucmar		Cañaypata		Macullida		Soledad	
		M	W	M	W	M	W	M	W	M	W
Resistance to LB	Flowering	1*	1	1	2	2	3	3	1	1	1
Resistance to Andean potato weevil	Flowering	2	3			4	4	1	2		
Abundant foliage	Flowering	3	2			3	1				
Drought tolerance	Flowering	4	4								
Vigorous plants	Flowering				1						
Many stems	Flowering				2						
Potato black leg resistant	Flowering			2							
Abundant flowering	Flowering			3							
Frost tolerance	Flowering					1	1	3	3	2	2
Early varieties	Flowering						2	2			
Thick stems	Flowering									3	3
High tuber yield	Harvest	1	2	2	1	1	2	1	1	1	2
White/yellow tuber skin colour	Harvest	2						2	3	2	
Uniform tuber size	Harvest			1						3	
Red tuber skin colour	Harvest			3	3						
Superficial eyes	Harvest	3	1					2	2		
Many eyes	Harvest				2						
Tubers shape elongated	Harvest						3				
Tolerance to Andean potato weevil	Harvest					3	1				1
Wart resistance	Harvest					2					
Floury and nutritious tubers	Harvest						4				2

M men, *W* women

*Order of merit 1 = excellent, 2 = very good, 3 = good, 4 = moderate

Table 6 Ranking of clones at flowering and harvest stages based on the selection criteria prioritised by farmers through the PVS, 2016–2017

Clones/varieties	Flowering stage										Harvest stage									
	CHA		CAN		MAC		CHU		SOL		CHA		CAN		MAC		CHU		SOL	
	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W
CIP308427.194			4*	4																
CIP308433.101					2															
CIP308436.173	3	3			1	1					3	3			3					
CIP308436.245						3														
CIP308436.84	1	2	3	3								4	4	4		4				
CIP308447.74																				
CIP308478.59	4				3						1	2			1	2				
CIP308480.298			2																	
CIP308481.314	2	1									3				2	1				
CIP308486.187															4	3				
CIP308486.221						2					2	1	3	2						
CIP308486.314																	4	4		
CIP308486.355							4	1	2	3								2		
CIP308487.157																	1	1		
CIP308487.157							1	1		1										
CIP308487.390							3	2												
CIP308488.198							2	1												2
CIP308488.92									3								2	3		4
CIP308495.227																	3		3	5
CIP308499.143									4	2										
CIP308502.95										1										
CIP308505.377									1	3										
CIP308513.318																			2	
CIP308519.110																				1
Yungay				2									2	3					1	3
INIA-302 Amarilis	3	4									4	5								
INIA-303 Canchan			1	1									1	1						

CHA Chaqui, *CHU* Chucmar, *CAN* Cañaypta, *MAC* Macullida, *SOL* La Soledad, *M* men, *W* women

*Order of merit in ranking 1 = excellent, 2 = very good, 3 = good, 4 = moderate

In Chucmar, men also identified resistance to black leg (*Erwinia* spp.) as an important criterion because this location has high rain-induced humidity in soil, which favours the presence of other diseases as well as LB (Table 5). The clones CIP308487.157, CIP308488.198, CIP308487.390 and CIP308486.355 were selected by men and women, but in different order in the ranking of preference (Table 6).

In Cañaypata, located above 3500 masl, both men and women selected frost tolerance and abundant foliage as important criteria for the ability to recover after damage due to low temperatures. The varieties 'INIA-303 Canchan' and 'Yungay' were selected as best performing, followed by CIP308436.84 and CIP308427.194 (Table 6). The varieties were selected by farmers due to their superior adaptation to highlands more than 3500 masl.

In Macullida and Soledad, also above 3500 masl, both men and woman identified frost tolerance as an important criterion. In La Soledad, men and women selected the clones CIP308505.377, CIP308486.355 and CIP308499.143; the clone CIP308488.92 was selected only by men; and clones CIP308502.95 and CIP308487.157 were selected by women. In Macullida, the clone CIP308436.173 was selected by men and women, the clones CIP308433.101 and CIP308478.59 were selected by men and the clones CIP308436.245 and CIP308476.221 were selected by women (Table 6).

The ranking of the clones in this phenological phase was carried out based on the preferences of the farmers according to the selection criteria identified in each locality. The main criterion was resistance to LB in all localities (Tables 5 and 6).

At Harvest

The breakdown of participation by location and gender is provided in Table 4. In all sites, both men and women identified tuber yield as the most important selection criteria.

In Chaquil, men said tubers should be white or yellow tuber skin colour with shallow eyes whilst women preferred that tubers should be resistant to weevil and mealy in addition to tuber yield (Table 5). Based on the selection criteria, most of the men selected clones CIP308436.173, CIP308848.314, CIP308478.59 and CIP308486.221, whilst most women selected CIP308436.173, CIP308486.221, CIP308447.74 and CIP308436.84. Both men and women selected the variety INIA-302 Amarilis. The BLUPs for yield of marketable tubers in Chaquil were in the range 8.99 to 18.34 t ha^{-1}, against the Yungay and Inia-302 Amarilis controls with 14.70 and 15.24 t ha^{-1}, respectively (Tables 6 and 8).

In Chucmar men preferred that tubers should be uniform in size and women that tubers should have enough eyes; both men and women preferred red skin tuber colour (Table 5). Clones CIP308486.314, CIP308487.157 and CIP308488.92 were selected by men and women according to the selection criteria identified as important. Clone CIP308486.355 was selected only by the women and clone CIP308495.227 was selected only by the men. Marketable tuber yield was from 12.18 to 37.05 t ha^{-1} with the control varieties Yungay and INIA-302 Amarilis at 14.20 and 37.05 t ha^{-1} (Tables 6 and 8).

In Macullida both men and women identified that the tubers should have white or yellow tuber skin colour and superficial eyes, as important characteristics after yields. Men and women selected clones CIP308478.59, CIP308481.314 and CIP308486.187; the clone CIP308486.173 was selected by men; and CIP308436.84 selected by women. The yield of marketable tubers in Macullida was in the range of 18.06 to 51.30 t ha^{-1}, against the Yungay and INIA-302 Amarilis controls with 49.41 and 45.86 t ha^{-1}, respectively (Tables 6 and 8).

In Soledad, men preferred uniform tuber size and white or yellow tuber skin colour and women preferred tolerance to Andean Potato Weevil and floury and nutritious tubers. Men selected clone CIP308513.318 and variety Yungay; whilst women selected clones CIP308519.110, CIP308488.92 and CIP308488.198; and both men and women selected clone CIP308495.227. Marketable tuber yield was from 14.58 to 53.15 t ha^{-1} versus the control varieties Yungay and INIA-302 Amarilis with 39.17 and 47.30 t ha^{-1}, respectively (Tables 6 and 8).

In Cañaypata, men and women selected high tuber yield and tolerance to Andean potato weevil as the most important criteria. In addition men preferred wart resistance and women preferred tubers shape elongated, floury and nutritious tubers. Based on these criteria, both men and women selected the clones CIP308486.221 and CIP308436.84 and varieties INIA-303 Canchan and Yungay. The yield of marketable tubers was in the range 5.61 to 20.71 t ha^{-1}, against the Yungay and INIA-303 Canchan controls with 19.20 and 33.61 t ha^{-1}, respectively (Tables 5 and 6).

The combined analysis of variance for the marketable tuber yield per hectare, in experiments 1 and 2, reveals significant statistical differences for environments, clones and the interaction clones × environments ($P < 0.01$) (Table 7). The marketable tuber yield of the clones was different across the localities. Some clones showed interaction with the localities; for example, in Chaquil the yields were low in relation to Chucmar, Macullida and Soledad, possibly because this locality had a period of drought caused by an abnormal rain regime during the development of the experiment. The same could have happened in Cañaypata because it is located near 4000 m above sea level, and probably the clones do not adapt to these altitudes. Some clones show yields acceptable in all localities and other clones had a significant G × E interaction such as the clones CIP308431.273, CIP30847.194 and CIP308505.377 and the Yungay variety, susceptible to late blight, that presented low yields in Chucmar, where the late blight pressure was very high as shown in Table 8.

The Waller–Duncan means comparison test ($P < 0.01$) is shown in Tables 8 and 9. In combined analysis, the BLUPs for marketable tuber yield values of the clones ranged from 12.40 to 40.55 t ha^{-1}; in experiment 1, clones CIP308478.59, CIP308436.84 and CIP308433.351 yielded 27.97, 21.92 and 21.82 t ha^{-1}, respectively; and in experiment 2, clones CIP308486.355, CIP308495.227 and CIP308488.198 yielded 40.55, 40.20 and 39.89 t ha^{-1}, presenting the highest values of marketable tuber yield, respectively.

The content of glycoalkaloids in a sample of clones ranged from 0.84 to 63.84 mg/100 g fresh weight. The clones CIP308436.173 and CIP308481.314 exhibited high

Table 7 Combined analysis of variance for marketable tuber yield per hectare (t ha^{-1})

Source of variation	Exp. 1		Exp. 2	
	df	Mean square	df	Mean square
Environments	2	8189.06**	1	5668.68**
Replication/environments	9	34.38	6	140.57
Clones	20	412.38**	19	571.84**
Clones × environments	37	228.49**	19	193.64**
Pooled error	171	36.50	114	33.75
C.V. %	30.25		20.68	

df degrees of freedom

**Statistically significant at $\alpha = 0.01$

Table 8 Mean comparison amongst BLUPs for marketable tuber yield by locations

Experiment 1 (t ha^{-1})							Experiment 2 (t ha^{-1})				
Clone	CHA		MAC		CAN		Clone	SOL		CHU	
Amarilis	15.24	defg	45.86	a	26.25	b	CIP308495.227	53.15	a	27.26	cde
Canchan	17.07	b	64.71	a	33.61	a	Yungay	39.17	def	14.20	i
CIP308478.59	16.33	bc	51.30	b	16.28	c	Amarilis	47.30	ab	37.05	a
Yungay	14.70	cdefg	49.41	b	19.20	b	CIP308486.355	45.03	abc	36.08	ab
CIP308486.187	13.85	defg	36.64	c	11.81	efg	CIP308513.318	44.85	bcd	26.29	cdef
CIP308436.173	17.85	b	34.83	c	11.78	efg	CIP308486.333	44.08	bcd	29.36	cd
CIP308433.160	10.95	ghi	34.78	c	10.21	fgh	CIP308488.198	43.57	bcde	36.21	ab
CIP308433.351	16.22	bcde	34.21	c	15.03	cde	CIP308487.157	40.88	bcde	30.85	bc
CIP308481.314	16.58	bcdef	32.03	cd	9.60	fgh	CIP308488.92	40.35	cdef	26.83	cde
CIP308436.84	17.71	b	31.62	cd	16.44	c	CIP308486.314	38.51	def	28.88	cd
CIP308486.221	15.51	cdefg	31.42	cd	13.96	cdef	CIP308505.377	36.41	efg	14.23	hi
CIP308480.298	16.41	bcd	31.29	cd	13.56	def	CIP308495.237	36.36	efg	21.47	efg
CIP308436.245	16.49	bcd	31.04	cd	13.77	def	CIP308487.390	34.19	fgh	23.79	defg
CIP308476.16	18.34	a	26.85	de	10.31	efg	CIP308519.110	32.70	fgh	19.75	efg
CIP308447.74	12.67	efgh	26.80	de	5.61	h	CIP308513.96	28.49	ghi	17.27	ghi
CIP308480.292	17.69	b	25.28	de	10.09	efg	CIP308492.207	26.18	hi	22.16	efg
CIP308427.194	9.40	hi	23.93	def	20.71	b	CIP308502.95	25.86	hi	18.75	fgh
CIP308431.273	9.87	hi	20.88	ef	6.66	gh	CIP308499.14	22.18	ij	23.26	defg
CIP308478.123	8.99	hi	20.17	ef	12.26	def	CIP308517.91	19.79	ij	15.57	ghi
CIP308433.101	14.60	cdefg	19.82	ef	9.77	fgh	CIP308499.76	14.68	j	12.18	i
CIP308441.227	9.08	hi	18.06	efg	10.06	efg					

*Clones and varieties with the same letter are not statistically different by Waller–Duncan test ($P > 0.05$)

glycoalkaloid content, exceeding the maximum allowed value of 20 mg/100 g fresh weight (Table 10).

The results of the organoleptic test carried out within the PVS methodology show us that there are clones that, according to the preference of farmers, have a good taste (grade 3). The clone CIP308478.59 was the only one that had a qualification of excellent (grade 5), being selected for the second phase of the study (Table 11).

In all localities, the most important selection criteria preferred by farmers for the selection of clones as future varieties, and providing very valuable information for breeders, were resistance to late blight and high tuber yield.

The clones CIP308478.59, CIP308486.355, CIP308488.198, CIP308488.92 and CIP308495.227 were selected, based on the results of the participatory evaluation (PVS), where they should have been selected at flowering and/or harvest by men and/or women to meet the most important criteria preferred by farmers. Good organoleptic quality, marketable tuber yield and low glycoalkaloid content (less than 20 mg/100 g fresh weight) were also taken into account (Table 12).

These clones were evaluated again in the 2017–2018 season, to select clones with high potential to become varieties.

Table 9 Mean comparison amongst BLUPs for marketable tuber yield in experiment 1 averaged over three locations and in experiment 2 over two locations

Experiment 1			Experiment 2		
Clone/variety	t ha^{-1}	Mean comparison	Clone/variety	t ha^{-1}	Mean comparison
INIA-303 Canchan	38.46	a	AMARILIS	42.12	a
INIA-302 Amarilis	37.18	a	CIP308486.355	40.55	a
CIP308478.59	27.97	b	CIP308495.227	40.20	a
YUNGAY	27.79	bc	CIP308488.198	39.89	a
CIP308436.84	21.92	bcd	CIP308486.333	36.72	ab
CIP308433.351	21.82	bcd	CIP308487.157	35.87	ab
CIP308436.173	21.49	bcd	CIP308513.318	35.57	bc
CIP308486.187	20.77	bcd	CIP308486.314	33.69	bcd
CIP308436.245	20.43	def	CIP308488.92	33.59	bcde
CIP308480.298	20.42	defg	YUNGAY	30.79	cdef
CIP308486.221	20.30	defg	CIP308487.390	28.99	defg
CIP308481.314	19.43	defg	CIP308495.237	28.91	efgh
CIP308433.160	18.65	defgh	CIP308519.110	26.22	fghi
CIP308476.16	18.50	efgh	CIP308505.377	25.32	ghi
CIP308427.194	18.02	fghi	CIP308492.207	24.17	ghi
CIP308480.292	17.65	fghij	CIP308513.96	22.88	hij
CIP308447.74	15.03	ghij	CIP308499.143	22.72	hij
CIP308433.101	14.73	hij	CIP308502.95	22.31	ij
CIP308478.123	13.80	ij	CIP308517.91	17.68	j
CIP308431.273	12.47	ij	CIP308499.76	13.43	k
CIP308441.227	12.40	j			

*Clones and varieties with the same letter are not statistically different by Waller–Duncan test ($P > 0.05$)

PVS Evaluation 2017–2018

At Flowering

Twenty-eight farmers (16 men and 12 women) participated in Chucmar at flowering, 16 farmers (8 men and 8 women) in La Aurorita, 11 farmers (5 men and 6 women) in Arcopampa and 25 farmers (11 men and 14 women) in Canaypata, Huancavelica.

Men and women in Chucmar, Aurorita and Arcopampa, and only men in Cañaypta, identified resistance to LB as the most important criteria of selection, which aligns with the results obtained in previous studies in Peru (Janampa 2012; Zuñiga et al. 2018). In Chucmar, both men and women identified that plants should have many vigorous stems, but women added that new varieties should have resistance to Andean potato weevil. In Aurorita and Arcopampa, both men and women identified tall plants and compact foliage, whilst in Arcopampa they identified resistance to Andean potato weevil. In Cañaypata, men preferred small leaves and hailstorm-tolerant varieties whilst women selected frost tolerance, small leaves and tall plants as the most important

Table 10 Glycoalkaloid content in B3C3 clones 2016–2017

Clones/variety	Glycoalkaloid content (mg/100 g fresh weight)				
	Chaquil	Macullida	Cañaypata	Chucmar	Soledad
CIP308427.194	6.53	2.57	6.82		
CIP308433.101	3.38	3.42	3.20		
CIP308433.160	6.05	6.48	5.56		
CIP308433.351	8.72	6.88	7.28		
CIP308436.173	27.74	17.01	23.97		
CIP308436.84	19.73	8.62	13.28		
CIP308478.123	1.26	0.84	1.45		
CIP308478.59	4.28	3.77	5.83		
CIP308480.292	7.71	3.20	5.79		
CIP308481.314	60.07	63.84	63.00		
CIP308486.187	6.19	2.52	5.66		
CIP308486.221	16.85	10.39	15.28		
CIP308486.314				2.03	5.74
CIP308486.333				6.99	16.83
CIP308486.355				7.04	12.93
CIP308487.157				3.70	6.16
CIP308488.198				5.25	12.72
CIP308488.92				3.77	6.78
CIP308495.227				2.06	14.87
CIP308502.95				11.16	7.91
INIA-302 Amarilis	4.40	2.70		1.22	3.34
INIA-303 Canchan			7.87		
Yungay	6.28	1.97	5.75	2.14	4.39

criteria in the flowering phase. The selection of frost tolerance as an important criterion aligns with results from Arcos et al. (2015) which also came from a site located above 3500 masl (Table 13).

At Harvest

In Chucmar, 24 farmers (16 men and 8 women) participated in PVS at harvest. Both men and women identified resistance to LB, good yield and good quality for market as the most important criteria. Women also preferred tubers with good taste. On this basis, clones CIP308488.92, CIP308495.227 and CIP308478.59 were selected by both men and women (Table 14). Marketable tuber yield of the three selected clones was higher than the two control varieties, INIA-302 Amarilis and Yungay, which were both affected almost 100% by LB. The clones CIP308495.227, CIP308488.92 and CIP308478.59 yielded 31.52 t ha^{-1}, 35.16 t ha^{-1} and 33.24 t ha^{-1}, respectively, against Yungay and INIA-302 Amarilis at 5.00 and 8.23 t ha^{-1}, respectively (Table 16). The organoleptic test showed that the clones CIP308495.227 and

Table 11 Organoleptic test in B3C3 clones by locality at harvest with PVS methodology

Clone	Flavour					
	Macullida	Soledad	Chucmar	Chaquil	Cañaypata	Experiment
CIP308427.194	1			3	3	1
CIP308431.273	1			1	3	1
CIP308433.101	1			3	3	1
CIP308433.160	1			1	3	1
CIP308433.351	1			1	3	1
CIP308436.173	1			1	1	1
CIP308436.245	1			1	1	1
CIP308436.84	1			3	3	1
CIP308441.227	3			1	3	1
CIP308447.74	1			1	3	1
CIP308476.16	1			1	3	1
CIP308478.123	3			3	3	1
CIP308478.59	1			1	5	1
CIP308480.292	1			1	3	1
CIP308480.298	1			1	1	1
CIP308481.314	1			3	1	1
CIP308486.187	1			1	3	1
CIP308486.221	3			3	1	1
CIP308486.314		1	1			2
CIP308486.333		3	3			2
CIP308486.355		1	3			2
CIP308487.157		3	1			2
CIP308487.390		3	1			2
CIP308488.198		1	1			2
CIP308488.92		3	3			2
CIP308492.207		1	1			2
CIP308495.227		3	3			2
CIP308495.237		1	3			2
CIP308499.143		1	1			2
CIP308499.76		3	3			2
CIP308502.95		1	5			2
CIP308505.377		1	1			2
CIP308513.318		1	3			2
CIP308513.96		3	1			2
CIP308517.91		3	1			2
CIP308519.110		1	1			2

1 = intermediate, 3 = good, 5 = excellent

Table 12 Selected B3C3 clones for experiments in next season 2017–2018

#	Clone	Selected PVS										Maketable tuber yield (t/ha)
		Flowering					Harvest					
		CHC	SOL	MAC	CHQ	CAN	CHC	SOL	MAC	CHQ	CAN	CHC
1	CIP308478.59			Yes	Yes				Yes	Yes		
2	CIP308486.355	Yes	Yes				Yes					36.08
3	CIP308488.198	Yes						Yes				36.21
4	CIP308488.92		Yes				Yes	Yes				26.83
5	CIP308495.227						Yes	Yes				27.26

#	Maketable tuber yield (t/ha)				Organoleptic test (flavour)					Glycolalkaloid content (mg/100 fresh weight)				
	SOL	MAC	CHQ	CAN	CHC	SOL	MAC	CHQ	CAN	CHC	SOL	MAC	CHQ	CAN
1		16.31	51.30	16.28			1	1	5			4.28	3.77	5.83
2	45.03				3	1				7.04	12.93			
3	43.57				1	1				5.25	12.72			
4	40.35				3	3				3.77	6.78			
5	53.15				3	3				2.06	14.87			

CHA Chaqui, *CHU* Chucmar, *CAN* Cañaypta, *MAC* Macullida, *SOL* La Soledad

Table 13 Main selection criteria identified in PVS trials at flowering and harvest stages, 2017–2018

#	Selection criteria	Stage	Chucmar Cajamarca		Aurorita La Libertad		Arcopampa La Libertad		Cañaypata Huancavelica	
			M	W	M	W	M	W	M	W
1	Resistance to LB	Flowering	1*	2	1	1	1	1	1	
2	Many stems	Flowering	2							
3	Broad leaved	Flowering								
4	Tall plants	Flowering			2	2	2	2		3
5	Compact foliage	Flowering				3	3	3		
6	Medium size plants	Flowering								
7	Many flowers	Flowering			3	3				
8	Resistant to the weevil	Flowering		3			3	3		
9	Vigorous stem	Flowering	3	1						
10	Small leaves	Flowering							2	1
11	Tolerant to hailstorm	Flowering							3	
12	Frost tolerant	Flowering								2
13	Dry leaves	Flowering								3
1	Good yield	Harvest	2	2	3	3	2	1	1	1
2	Big tubers	Harvest			2	2	3	2	2	4
3	Resistance to LB	Harvest	1	1	1	1	1	3		2
4	Good quality for market	Harvest	3	3						
5	Tuber of two colours	Harvest							3	
6	Resistant to other disease	Harvest					3	1		
7	Yellow flesh colour	Harvest		2						
8	Palatability	Harvest		3						
9	Resistant to the weevil	Harvest	3							3

*Order of merit 1 = excellent, 2 = very good, 3 = good, 4 = moderate

CIP308478.59 had good flavour on par with INIA-302 Amarilis and Yungay. The glycoalkaloid content was low, ranging from 2.01 up to 5.35 mg/100 g of fresh weight (FW), less than the limit value of 20 mg/100 g FW (Table 14).

In La Aurorita, 16 farmers (7 men and 9 women) participated in PVS during harvest. Both men and women identified resistance to LB, big tubers and high tuber yield as the most important selection criteria. Men selected clones CIP308495.227, CIP308488.92 and CIP308488.198 with 34.09 t ha^{-1}, 37.26 t ha^{-1} and 38.34 t ha^{-1}, respectively, and women also selected clone CIP308486.355 with 35.57 t ha^{-1}. Marketable tuber yield of these clones was higher than controls INIA-303 Canchan and INIA-302 Amarilis with 25.46 and 21.02 t ha^{-1}, respectively. The yield of INIA-302 Amarilis grown in La Aurorita was higher than in Chucmar because the LB pressure in this site was lower (Table 16). The organoleptic test, carried out by the farmers, showed that clones CIP308488.92 and CIP388495.227 had good flavour on par with INIA-303 Canchan. The content of glycoalkaloids was low and ranged from 3.59 to 6.67 mg/100 g FW, less than the limit value of 20 mg/100 g FW (Table 14).

Table 14 PVS ranking at harvest, glycoalkaloid content and organoleptic test—flavour in B3C3 clones, 2017–2018

Clone	LB resistance	PVS ranking at harvest				Glycoalkaloid content (mg/100 g fresh weight)				Organoleptic test—flavour				Selected
		CHU	AUR	ARC	CAN	CHU	AUR	ARC	CAN	CHU	AUR	ARC	CAN	
CIP308478.59	Resistant	3			3	3.61	5.58	6.22	8.55	Good				Yes
CIP308488.198	Resistant		3	3		2.97	4.05	14.40	13.46			Good		
CIP308488.92	Resistant	1	2			2.01	5.95	7.54	17.92		Good	Good		Yes
CIP308486.355	Resistant			1		5.35	4.05	10.06	30.13					
CIP308495.227	Resistant	2	1	3		2.71	6.67	11.63	9.52	Good	Good	Good	Good	Yes
INIA-302 Amarilis	Moderately			2	2					Good		Good	Good	
INIA-303 Canchan	Susceptible				1					Good	Good		Good	

1, 2 and 3 = first, second or third place in the ranking of farmers' preferences based on the selection criteria identified by them to select a new variety

CHU Chucmar, *AUR* Aurorita, *ARC* Arcopampa, *CAN* Cañaypata, *LB* late blight

In Arcopampa, 14 farmers (8 men and 6 women) participated in PVS during harvest. Both men and women identified resistance to LB, big tubers and high tuber yield as the most important traits (Table 13). Men identified clones CIP308486.355, CIP308495.227 and CIP308488.198 with 18.95, 19.51 and 18.51 t ha^{-1}, respectively, and women selected clone CIP308478.59 (with 19.54 t ha^{-1}) and the varieties INIA-303 Canchan and INIA-302 Amarilis. Marketable tuber yield of the selected clones was less than Amarilis and Canchan (21.66 and 20.94 t ha^{-1}, respectively). The yields of the selected clones were lower, probably due to the high altitude of this place, and the clones did not adapt to these conditions (Table 16). The organoleptic test carried out by the farmers shows that clones CIP308495.227, CIP308488.198 and CIP308488.92 had a good flavour on par with INIA-303 Canchan. The content of glycoalkaloids was low and ranged from 6.22 to 14.40 mg/100 g FW, less than the limit value of 20 mg/100 g FW (Table 14).

In Cañaypata, 29 farmers (14 men and 15 women) participated in PVS during harvest. Men identified high tuber yield, big tubers and tubers with two skin colour as most important criteria. Women chose high yield, resistance to LB and Andean potato weevil as the most important criteria (Table 13). Men and women identified varieties Yungay and INIA-303 Canchan and the clone CIP308478.59 as best, with 31.45, 20.57 and 11.63 t ha^{-1}, respectively (Table 16). The organoleptic test, carried out by the farmers, showed that clone CIP308495.227 had good flavour on par with INIA-303 Canchan and Yungay (Table 14). The yields of the selected clones were low, likely due to the fact that the clones were not adapted to altitudes above 3700 masl and because the experiment was affected by frost twice during the growing period. The content of glycoalkaloids ranged from 8.55 to 30.13 mg /100 g FW (Table 14). The clone CIP308486.355 showed a very high level of glycoalkaloids (30.13 mg /100 g FW) in Cañaypata, almost 50% above the safe limit in tubers. This high value is likely due to the fact that this clone was more susceptible to frost and the high content of glycoalkaloids were produced as a reaction to the stress produced by low temperatures during the experiment (Table 14).

In all locations, good tuber yield was identified as an important selection criterion, which matches the finding of other research in Peru (Janampa 2012; Arcos et al. 2015; Zuñiga et al. 2018), confirming that potato varieties adapted to mid-elevation and highland environments should be resistant to LB and offer good tuber yield (Table 13). These criteria were used by farmers in the PVS methodology to identify the three best clones for their preference.

Clones CIP308495.227 and CIP308488.92 were selected in Chugmar and Aurorita, but not in Arcopampa and Cañaypata. The last two locations are above 3900 masl and the clones are better adapted to lower altitudes. The clone CIP308478.59 was selected in Chugmar and Canaypata, showing a wider adaptation to low and high altitudes (Table 14). These results are consistent with Semagn et al. (2017). Overall, our findings indicate that no variety possesses all desirable characteristics and that there is a need for selecting varieties adapted to different agroecologies and growing seasons. Further studies should take farmer interests into account for a highly heterozygous, clonally propagated crop like potato to be accepted by farmers. The differences in adaptation are probably the result of the population improvement that was carried out in CIP, where the aim is to maintain a wide gene and genotypic variability.

The combined analysis of variance for marketable tuber yield per hectare shows statistically significant differences ($P < 0.01$) for the environments, clones and interaction clones × environments (Table 15). The coefficient of variation at 30.79% was within the acceptable range.

The clone × environment interaction was probably due to the contrasting environments where the experiments were planted. In Chucmar and Aurorita, the marketable yield was higher than in Arcopampa and Cañaypata, which are located at altitudes greater than 3700 masl with the presence of frost, and most clones do not adapt well to these conditions. Another factor was the high pressure of late blight in Chucmar where Yungay and Amarilis were strongly affected by this disease, resulting in very low yields, compared to the locations where late blight pressure was lower (Table 16).

After analysing the results of PVS and tuber yields using mixed models and BLUPs, and considering good organoleptic quality and low glycoalkaloid content, three clones were selected, CIP308488.92, CIP308495.227 and CIP308478.59 with 24.75, 24.16 and 24.68 t ha^{-1}, respectively.

The clones CIP308488.92 and CIP308495.227 were selected based on the preference of the farmers during the participatory varietal selection (PVS) at harvest in Chucmar and Aurorita, their low content of glycoalkaloids, good quality of flavour in the organoleptic test in Arcopampa and Aurorita for the first clone and across all locations for the second clone, combined with high average yields from all locations. These clones are recommended as promising for new varieties at midelevation or in environments below 3500 masl in highlands in sub-Saharan Africa (Rwanda, Kenya, Ethiopia), South Asia (Nepal, Bhutan) and in the Andean zone of Latin America and may show good adaptation where there is no frost and the main problem is LB (Table 14). However, more trials are needed before recommendation for any of these clones to be registered as new varieties.

The clone CIP308478.59 was selected for its wider adaptation. It was selected by farmers through PVS in two contrasting environments Chucmar and Cañaypata. Its good taste was also considered in the organoleptic test in Chucmar and its low content of glycoalkaloids. This clone could be an alternative for environments located above 3700 masl, in the Andean zone of Latin America. However, there is a need to evaluate a new set of LB-resistant clones that also show tolerance to frost to have a better pool of clones for farmer selection.

Table 15 Combined analysis of variance for marketable tuber yield (t ha^{-1})

Source of variation	df	Mean square
Environments	3	1978.46**
Replications/environments	12	15.46
Clones	7	187.99**
Clones × environments	17	319.86**
Error	72	28.35

C.V. = 30.79%

**Statistically significant at $P < 0.01$ *df* = degrees of freedom

Table 16 Mean comparison amongst BLUPs for marketable tuber yield

Clone	BLUP marketable tuber yield (t ha^{-1})				
	Chucmar Cajamarca	Aurorita La Libertad	Arcopampa La Libertad	Cañaypata Huancavelica	Combined
CIP308478.59	33.24 a*	34.31 abc	19.54 ab	11.62 c	24.68 a
CIP308486.355	26.52 b	35.57 abc	18.95 ab	8.02 cd	22.26 a
CIP308488.198	31.83 a	38.34 a	18.51 abc	5.23 c	23.48 a
CIP308488.92	35.16 a	37.26 a	18.91 bc	7.69 cd	24.75 a
CIP308495.227	31.52 a	34.09 abc	19.51 c	11.51 cd	24.16 a
INIA-302 Amarilis	8.23 c	21.02 c	21.66 c		19.00 b
INIA-303 Canchan		25.46 bc	20.94 a	20.57 b	20.85 a
Yungay	5.00 c			31.45 a	18.84 b

*Clones and varieties with the same letter are not statistically different in Waller–Duncan test ($P > 0.05$)

Conclusions

In all localities, using PVS methodology, both men and women identified resistance to LB during flowering and high tuber yield during harvest as the most important selection criteria for new potato varieties.

In Arcopampa and Cañaypta, located more than 3900 masl, frost tolerance and resistance to the Andean weevil were also identified as important selection criteria.

The clones CIP308488.92 and CIP308495.227 were selected as promising clones in Chucmar Cajamarca and La Aurorita La Libertad, locations situated at 2800 and 3700 masl, respectively. In these two locations, these clones had a high resistance to LB and high tuber yield superior to local varieties, INIA-303 Canchan, Yungay and INIA-302 Amarilis, which are susceptible to LB. These clones also have good organoleptic quality and low glycoalkaloid content. The clone CIP308478.59 was selected as promising in Chucmar and Cañaypata, given its wider adaptation. These clones selected as promising should continue trials before they can be recommended for variety registration in mid-elevation and highland environments globally.

Acknowledgements The authors would like to thank Bert de Boeck for statistical support.

Funding This publication has been produced with the financial assistance of the European Union within the framework of the Benefit-sharing Fund project "Biodiverse and Nutritious Potato Improvement across Peru, Nepal and Bhutan" of the FAO's International Treaty on Plant Genetic Resources for Food and Agriculture. This research was undertaken as part of, and funded by, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and by USAID, supported by CGIAR through the CGIAR Trust Fund Donors (https://www.cgiar.org/funders/).

Declarations

Disclaimer The views expressed in this document are those of the authors and do not necessarily reflect the views or policies of the European Union or FAO.

References

Abebe GK, Bijman J, Pascucci S, Omta O (2013) Adoption of improved potato varieties in Ethiopia: the role of agricultural knowledge and innovation system and smallholder farmers' quality assessment. Agric Syst 122:22–32. https://doi.org/10.1016/j.agsy.2013.07.008

Arcos J, Gastelo M, Holguin V (2015) INIA 317 – Altiplano, variedad de papa con buena adaptación en la región altiplánica del Perú. Revista Latinoamericana de la Papa 19(2):68–75. https://doi.org/10.37066/ralap.v19i2.234

Badstue LB, Hellin J, Berthaud J (2012) Re-orienting participatory plant breeding for wider impact. Afr J Agric Res 7(4). https://doi.org/10.5897/AJAR10.1146

Bajgai Y, Dochen T, Wangchuk P, Kadian MS, Felde zum T, Lefebvre M, Lobzang, Arya S, Wangdi T, Gyeltshen T, Wangdi N (2018) Participatory varietal selection of potato and agronomic performance with farmers' feedback on new varieties. Bhutanese Journal of Agriculture. ISSN 2616-3926. 12p

Burgos G, Sosa P, Zum Felde T (2014) Procedures for chemical analysis of potato and sweet potato samples at CIP's Quality and Nutrition Laboratory. Lima, Peru. International Potato Center (CIP), Global Program Genetics and Crop Improvement. 23 p

Butler DG, Cullis BR, Gilmour AR, Gogel BG, Thompson R (2017) ASReml-R Reference Manual Version 4. VSN International Ltd, Hemel Hempstead, HP1 1ES, UK

Cuesta X, Andrade H (2001) El Mejoramiento participativo de papa en el Ecuador. INIAP-PNRT-papa. PREDUZA Quito Ecuador

De Haan S, Salas E, Fonseca C, Gastelo M, Amaya N, Bastos C, Hualla V, Bonierbale M (2017) Selección participativa de variedades de papa (SPV) usando el diseño mama y bebe: una guía para capacitadores con perspectiva de género. Lima (Perú), Centro Internacional de la Papa 82pp

Egusquiza R (2000) La Papa. Producción, Transformación y Comercialización. Universidad Agraria La Molina. Convenio ADEX-AID/MSP. Lima, Perú.192 p

Gabriel J, Herbas J, Salazar M, Thiele G (2002) Manual Técnico de Mejoramiento Participativo para Obtener nuevas Variedades de Papa. Promoción e Investigación de Productos Andinos. Proyecto de Mejoramiento Participativo. PROINPA, Bolivia

Gilmour AR, Cullis BR, Verbyla AP (1997) Accounting for natural and extraneous variation in the analysis of field experiments. J Agric Biol Environ Stat 2(3):269–293

Janampa A (2012) "Participatory selection under the mother & baby design of 20 potato clones *Solanum tuberosum* spp. *andigena* (population B1C5), with horizontal resistance to late blight (*Phytophthora infestans*)." Thesis Agronomist, University for Andean Development. (in Spanish)

John JA (1989) Row–column designs. In: Cyclic Designs. Monographs on Statistics and Applied Probability. Springer, Boston, MA

Klawitter M, Cagley JH, Gugerty MK, Anderson CL, Yorgey G (2009) Gender and Cropping: Wheat in Sub-Saharan Africa. EPAR Research Brief #36. Seattle: University of Washington, Evans School of Public Affaird

Labarta R (2015). The effectiveness of potato and sweetpotato improvement programs from the perspectives of varietal output. Crop Improvement, Adoption and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa, p 164

Landeo JA, Gastelo M, Pinedo H, Flores F (2001) Breeding for horizontal resistance to late blight in potato free of R genes. In *Phytophthora infestans* 150 proceedings, Dublin Ireland. EAPR, Boole Press pp 268–274

Landeo JA, Gastelo MA, Pacheco MA, De Haan S, Diaz L, Puente de E (2008), Two new potato varieties (*Solanum tuberosum* ssp. *andigena*) with horizontal resistance to late blight selected by Andean communities through participatory variety selection. Poster presented at: Potato science for the poor; challenges for the new millennium. A working conference to celebrate the International year of the Potato, Cusco, Peru 25–28 March

Litschmann T, Hausvater E, Doležal P, Petra B (2018) Climate change and its impact on the conditions of late blight occurrence. Sci Agric Bohem 49:173–180. https://doi.org/10.2478/sab-2018-0023

Ministerio de Agricultura y Riego del Peru (2018) http://sissic.minagri.gob.pe/sissic. Accessed July 2020

Morris ML, Bellon MR (2004) Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. Euphytica 136:21–35. https://doi.org/10.1023/B:EUPH.0000019509.37769.b1

Mudege NN, Mukewa E, Amele A (2015) Workshop report: training on gender integrated potato participatory varietal selection (PVS) in Ethiopia. Addis Ababa, Ethiopia, CIP. 26 p

Pradel W, Hareau G, Quintanilla L, Suárez V (2017) Adopción e Impacto de Variedades Mejoradas de Papa en el Perú: Resultado de una encuesta a nivel nacional (2013). Centro Internacional de la Papa, Lima, Perú. pp 48

Ruprich J, Rehurkova I, Boon PE, Svensson K, Moussavian S, Van der Voet H, Bosgra S, Van Klaveren JD, Busk L (2009) Probabilistic modeling of exposure doses and implications for health risk characterization: glycoalkaloids from potatoes. Food Chem Toxicol 4:2899–2905

Semagn AK, Donald H, Keith P, Walter DJ, Fentahun MT, David W (2015) Identification of farmer priorities in potato production through participatory variety selection. Am J Potato Res 92:648–661. https://doi.org/10.1007/s12230-015-9478-0

Semagn AK, De Jong PK, Halseth D, Mengistu F (2017) Participatory variety selection: a tool to understand farmers' potato variety selection criteria. Open Agric 2:453–463. https://doi.org/10.1515/opag-2017-0049

Southeast Asia Regional Initiatives for Community Empowerment (2007) Valuing participatory plant breeding: a review of tools and methods. SEARICE, Manila, Philippines

Storey RMJ, Davies HV (1992) Tuber quality. In: Harris P (ed) The Potato crop, 2nd edn. Chapman & Hall, London, pp 507–569

Tesfaye TT (2013) Participatory variety selection of potato (*Solanum tuberosum* L) in southern Ethiopia. Journal of Agri-Food and Applied Sciences. On-line at jaas.blue-ap.org ©2013 JAAS J 1(1):1–4

Zuñiga N, Gastelo M, Bastos C, Reyes J, Alania D, Ninalaya E. (2018) Nuevos cultivares de papa con resistencia a la rancha *Phytophthora infestans* (Mont.) De Bary y adaptación al cambio climático Revista Latinoamericana de la Papa 22 (2): 66 - 82 ISSN: 1853-4961, https://doi.org/10.37066/ralap.v22i2.305

Affiliations

Manuel Gastelo[1] · Gabriela Burgos[1] · Carolina Bastos[2] · Juan Miguel Perez[3] · Ronal Otiniano[3] · Hector Cabrera[4] · Raul Ccanto[5] · Maria Mayer de Scurrah[5] · Thomas zum Felde[1]

[1] International Potato Center, Lima, Peru

[2] International Potato Center, Huancayo, Peru

[3] NGO Asociacion Pataz, La Libertad, Peru

[4] National Institute of Agrarian Innovation, Cajamarca, Peru

[5] NGO Yanapai, Huancavelica, Peru