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ORIGINAL ARTICLE

INIA 333 – CHUGAYNA new Potato Variety Resilient to Climate Change for the Family Farming System with Tolerance to Frost, Resistant to Late Blight and high Quality for Fresh Consumption

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Abstract
The new potato variety INIA 333–CHUGAYNA, is the result of the joint work of the NGO Asociación Pataz, INIA and the International Potato Center, it was generated through traditional breeding and the use of the participatory varietal selection methodology, as a variety resilient to climate change with frost tolerance, resistance to late blight, compared to the improved variety INIA 302-Amarilis and the native varieties, Huevo de Indio. This new variety is also resilient to climate change, tolerant to frost, with field resistance to late blight, high tuber yield, low glycoalkaloid content and high quality for fresh consumption, adapted up to 4000 m above sea level. It was released in 2023 and officially registered in the national registry of commercial varieties of Peru. The new variety INIA 333-CHUGAYNA requires minimal use of fungicides and has a high economic profitability that will improve the living standards of small and medium-sized farmers in Peru. It can also be used as a parent in breeding programs in other countries in development, to confront climate change, especially frost.

Resumen
La nueva variedad de papa INIA 333–CHUGAYNA, es el resultado del trabajo conjunto de la ONG Asociación Pataz, INIA y el Centro Internacional de la Papa, se generó a través del mejoramiento tradicional y el uso de la metodología de selección varietal participativa, como una variedad resiliente al cambio climático con tolerancia a las heladas, resistencia al tizón tardío, en comparación con la variedad mejorada INIA 302-Amarilis y las variedades nativas, Huevo de Indio. Esta nueva variedad también es resistente al cambio climático, tolerante a las heladas, con resistencia de campo al tizón tardío, alto rendimiento de tubérculos, bajo contenido de glicoalcaloides y alta calidad para el consumo en fresco, adaptada hasta los 4000 metros sobre el nivel del mar. Fue liberada en 2023 e inscrita oficialmente en el registro nacional de variedades comerciales del Perú. La nueva variedad INIA 333-CHUGAYNA requiere un uso mínimo de fungicidas y tiene una alta rentabilidad económica que mejorará el nivel de vida de los pequeños y medianos agricultores en el Perú. También puede ser utilizada como progenitor en programas de mejoramiento en otros países en desarrollo, para enfrentar el cambio climático, especialmente las heladas.

Keywords Papa · Variety · Climate change · Frost · Late blight · Family agriculture · Fresh consumption

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Introduction

Frost damage is of the main environmental stress one of the main factors that affect growth, development and production efficiency of the potato crop when it is planted in high areas where temperatures drop below 0°C (Tu et al. 2023), according to field observations, two types of frost are often distinguished, the "white frost" that occurs when there is a drop in temperature and the relative humidity is high and the "black frost" that occurs at low temperatures and in much drier conditions, so it is more harmful and serious, because the plant tissue darkens immediately. In South America, the areas with a high presence of frost are the central and southern Andes of Peru, the central Andes of Chile and the low areas of Argentina, where temperatures reach −3°C (Hijmans et al. 2003). In Peru, areas planted with potatoes in the Andes are constantly affected by frost, especially under climate change conditions, which can cause even the total loss of tuber yield. One of the alternatives to address this problem is the generation of varieties that are tolerant to frost and resilient to climate change. In Peru, the University of Wisconsin (USA) together with INIA obtained new frost-tolerant varieties for the Peruvian highlands, introducing the resistance of the wild species *Solanum commersoni* to native varieties of Solanum tuberosum spp andigena (Arcos et al. 2024). Frost also occurs on other continents such as Asia. In India, the Kufri Sheetman and Kufri Dewa cultivars have been identified as frost tolerant. coming from crosses with *Solanum acaule* that is highly resistant to frost (Li and Fennel 1985; Bhardwaj 2017) and can be used to generate new genotypes in breeding programs for frost tolerance. In a study carried out in China to evaluate the tolerance to low temperatures in wild potato species, in a cross population of *Solanum commersoni* (tolerant) with *Solanum verrucosum* (susceptible), they found that tolerance to frost under variable low temperature conditions is controlled by different loci (Dong et al. 2023; Pino and Chen 2016). Frost tolerance must be accompanied by high tuber yield and other quality characters for the market.

INIA 333–CHUGAYNA (CIP386714.6), is a variety registered by the NGO Asociación Pataz, the National Institute of Agrarian Innovation (INIA) of Peru and International Potato Center (CIP), as a product of evaluation and selection under field conditions using the participatory varietal selection methodology. (SVP), which includes the participation of the stakeholders in the value chain in two phenological phases of the crop, flowering and harvest, who give their opinions about the characteristics that the new variety should have, considering the gender of the participants, because opinions differ for some characteristics, for example, market value characteristics are more important for men and for women, characteristics related to culinary quality are more important. This information is analyzed and used in the evaluation of the new variety both at the level of agronomic and organoleptic characteristics and resistance to the main pests and diseases in the area of influence of the new variety (de Haan et al. 2017). This new variety INIA 333 - CHUGAYNA (CIP386714.6) generated by the International Potato Center (CIP) was obtained through traditional breeding, crossing the high frost-tolerant clone HFF14.3 as the female parent with the clone 575049 (CEW.69.1) as the parent male with resistance to late blight (Fig. 1). There is no further information available for the genealogy of female parent, as it is an old clone with high tolerance to frost, of which there are no records of its parents. It is only known that they were native potato varieties tolerant to frost, the HFF14.3 clone was selected for its high frost tolerance in the CIP Frost Tolerance Breeding Project, following all tests both at the greenhouse and field level (CIP 1986, 1987). The male parent was also released as a variety in Guatemala under the name ICTA Alaska (ICTA 2006) and in Venezuela as Caribay for its high yield and resistance to Late blight (León and Varela 1995). The crossings were made by the CIP at the Santa Ana experimental station in Huancayo, Peru (3288 m.a.s.l.) 12°0'33.9"S, 75°13'41.7"W) in 1986.

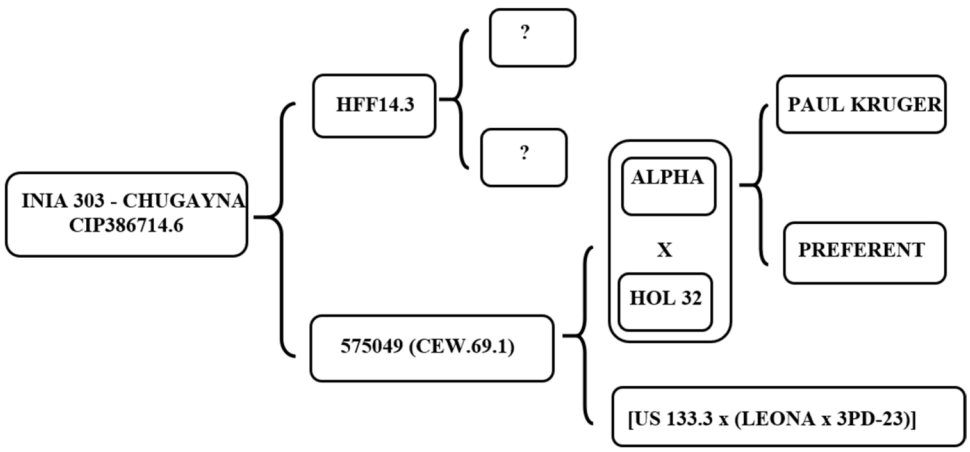

Fig. 1 Genealogy of the variety INIA 333 – CHUGAYNA

The initial evaluations of frost tolerance were carried out at the CIP in La Molina, Lima, Peru, the seedlings from botanical seed were evaluated in growth chambers at −4ºC for two hours, a week later the surviving seedlings were transplanted in the field in Huancayo at 3200 m.a.s.l. At harvest, the clones were selected for qualitative characteristics such as shape and number of tubers, skin color and uniformity. From 1990 to 1995, select clones were evaluated under field conditions in Usibamba, Huancayo, Junín (3800 m.a.s.l.) and in Illpa, Puno (3870 m.a.s.l.) in Peru, where the presence of frost is frequent during the crop growing season. potato, from October to May, allowing the clones to be exposed to severe frost stress, temperatures reach − 4 °C. Frost tolerance was taken as a percentage of leaf damage after the presence of frost and recovery capacity fifteen days later. Following this process, the new variety INIA 333–CHUGAYNA was selected (CIP 1986, 1987).

Resistance to late blight was evaluated from 1990 to 1996 under field conditions in Oxapampa (1814 m.a.s.l., 12°34′3″ S, 75°24′14″ W) and Comas, Junín (2550 m.a.s.l., 11°37′09 ″S 75°05′22″W), localities with optimal environmental conditions of relative humidity greater than 80% and more than 1000 mm of annual precipitation, to develop high pressure of the disease, resistance was measured with the AUDPC (Area under of the disease progress curve) (Forbes et al. 2014).

The new INIA 333–CHUGAYNA variety, in addition to frost tolerance, resistance to late blight and good tuber yield, has a high percentage of dry matter, a character that allows it to have high culinary quality. This variety has been registered in the national registry of commercial varieties, in the seed authority of Peru (SENASA) with registration N° 001–2022-MIDAGRI-SENASA-CAJAMARCA.

This new variety resilient to climate change will allow farmers to face the effects of climate change, due to the increase in pressure from adverse abiotic factors such as frost and biotic factors such as late blight that in recent years has been occurring in altitudes greater than 4000 m above sea level (Perez 2016; Giraldo et al. 2010; Quiroz et al. 2018), probably due to the increase in temperature. This variety can be included in the family farming system due to its comparative advantages with respect to traditional varieties planted in the country such as Yungay, Canchan, Amarilis, Única and others, improving the profitability and quality of life of small and medium-sized farmers.

Varietal Description

The information on the characteristics of the new variety INIA 333-CHUGAYNA was obtained from two Distinction, Homogeneity and Stability (DHE) trials, carried out in the 2013–2014 growing season in San Juan (36436 m.a.s.l.) and Macullida (3572 m.a.s.l.) in the Chugay district, Sánchez Carrión Province, La Libertad Region, Using the randomized complete block design with three replications of 20 plants each, 42 characteristics were evaluated as recommended by the Guidelines for the performance of the examination of distinctiveness, uniformity and stability in *Solanum tuberosum* L. (UPOV 2004).

Plants

Growth habit: semi-erect with intermediate type foliage, with intermediate maturity under Peruvian conditions (120 days from sowing to harvest) *Stems*: vigorous green with weak anthocyanin pigmentation (Fig. 2a).

Leaves

Large with intermediate opening, intermediate green in color, the pigmentation of the central vein is weak, the second pair of leaflets is very small, with absent or very low coalescence in terminal and lateral leaves (Fig. 2b).

Flowers

Flower bud with absent or weak anthocyanin pigmentation, small inflorescences, scarce flowering, pigmented peduncle joints. Corolla: small in size, pale lilac in color, semi-star-shaped, anthers and pistils without anthocyanins. It has fertile pollen and can be used as male and female parents in crosses (Fig. 2c).

Tubers

Oblong tuber shape, with superficial eyes, cream skin with red-purple eyes, cream flesh, 80 to 150 mm in length and

Fig. 2 INIA 333 – CHUGAYNA (a) Plant, (b) Leaves, (c) Flowers, (d) tubers

an average weight of 150 g per tuber, dormancy is 60 to 70 days stored under diffuse light at the temperature of 10 to 13ºC. The number of tubers is 10–11 per semi-compact tuber plant, high percentage of dry matter (17.52%), high quality for fresh consumption (Photo 2d). *Sprouts*: medium size, conical in shape, greenish-white with violet spots, the intensity and anthocyanin proportion at the base of the shoot is medium with medium pubescence at the base, the number of radicles medium.

Tuber Yield

The tuber yield was evaluated in comparative experiments in two regions with high incidence of frost during the growing season (October – May), The statistical design of randomized complete blocks was used with four repetitions of 10 plants each, the improved varieties Yungay and Pallayponcho and the native varieties Compis and Larga were used as controls. The yields were from 12.45 t/ha. In Anccaca (Puno) up to 45.22 t/ha in Laraqueri (Puno, The yields in Anccaca were low due to the presence of very severe frosts in the months of February and March 2007 (−4 °C), however the yield was higher to the Compis variety, the most common in the area (Table 1).

In the 2013–2014 and 2014–2015 growing seasons, 11 adaptation and efficiency trials were carried out in farmers' fields to meet the requirements of the Seed Authority (SENASA) in Peru (MINAGRI 2012), the trials were carried out in the north of Peru, in the La Libertad region, province of Sánchez Carrión. (Table 2) where the average temperature is 10 °C with a range of 5 °C to 19 °C during the year.

The complete randomized block design was used with three repetitions, each experimental unit had 100 plants, the improved variety INIA 302–Amarilis and the native varieties, Huevo de Indio, Peruanita, Bretaña and Perla were used as controls, as they were the varieties most common in the mountains of the La Libertad region, the planting density was 1.00 m between rows and 0.30 m between plants, the fertilization dose was 160-150-100 of N, P_2O_5 and K_2O peer ha. The sources used were: Urea (46%), Ammonium Phosphate (18% N and 46% P_2O_5) and Potassium Chloride (60% K_2O). The control of late blight was carried out with the application of systemic and contact fungicides up to six times in the control varieties, according to the pressure of the disease; while in the new variety it was only necessary to apply up to three times (Perez et al. 2020). In addition. To control insects such as the Andean weevil (Premnotrypes spp) and Epitrix spp, insecticides based on Fipronil, Cypermethrin and Betacyfluthrin were used, applied according

Table 1 Tuber yield of the INIA 333-CHUGAYNA variety in the regions of Puno and Huancavelica from 2006 to 2012. (Estrada 2000)

Clone	Puno			Huancavelica	
	2006–2007	2008–2009	2009–2010	2011–2012	
	Laraqueri	Anccaca	Camicachi	Ccasapata	Chopccapampa
CIP386714.6 INIA 333-CHUGAYNA	45.22 a	12.45 a	22.09 a	30.34 b	38.51 a
Compis	38.88 b	8.05 b	21.04 a		
Yungay				44.32 a	31.80 b
Pallayponcho				43.84 a	26.39 c
Larga				16.08 c	18.03 d

Table 2 Locations where adaptation and efficiency trials were carried out in Peru 2013–2015

Growing Season	Locality	District	Province	Región	Altitude m.a.s.l.
2013–2014	Macullida	Chugay	Sánchez Carrión	La Libertad	3700
	San Juan Bajo	Chugay	Sánchez Carrión	La Libertad	3580
	La Soledad	Chugay	Sánchez Carrión	La Libertad	3500
2014–2015	La Soledad	Chugay	Sánchez Carrión	La Libertad	3500
	Arcopampa	Chugay	Sánchez Carrión	La Libertad	3500
	San Juan Alto	Chugay	Sánchez Carrión	La Libertad	3800
	Canucubamba	Chugay	Sánchez Carrión	La Libertad	3550
	El Progreso	Chugay	Sánchez Carrión	La Libertad	3700
	Nuevo Huaycho	Chugay	Sánchez Carrión	La Libertad	3700
	San Francisco	Chugay	Sánchez Carrión	La Libertad	3700
	Pichauli	Chugay	Sánchez Carrión	La Libertad	3700

to the level of economic damage, previously evaluated. All experiments were planted under rainfed conditions in the rainy season (November to may). The agronomic management was the same as a commercial potato field. The harvest was carried out 120 days after sowing, taking the commercial and total weight of the tubers per experimental unit, which was converted to tons per hectare. In the trials of the 2014–2015 growing season, the participatory varietal selection (SVP) methodology was used to determine the comparative advantages of the new variety and the control varieties INIA 302–Amarilis and Huevo de Indio both in the field and in the organoleptic evaluation of tubers to harvest (Table 3).

The tuber yield of the INIA 333-CHUGAYNA variety on average in eleven locations was 47.11 t/ha. with a range of 36.85 t/ha. in Macullida (2013–2014) up to 54.73t/ha. in Soledad (2013–2014), in all locations except in Macullida (2013–2014) it was statistically different from the control varieties INIA 302-AMARILIS, Huevo de Indio, Peruanita, Bretaña and Perla with 27.35, 18.27, 12.12, 10.17 and 13.95 t/ha respectively ($p < 0$–05) (Table 4). It can be observed that the tuber yields of this new variety were consistent and phenotypically stable over time (years) and space (localities) (Vásquez et al. 2019), with standard deviation of 4.84 compared to the variety INIA 302-AMARILIS with a standard variation of 12.67 and Huevo de Indio with 7.48. (Table 4).

Frost Tolerance

Climate change is causing negative effects for agriculture, among them we have the increase in the frequency of frost associated with droughts and erratic rainfall regime (Quiroz et al. 2018), it is estimated that damage from frost can cause up to 100% of loss of yield (Yucra 2006) depending on the severity and intensity of the frosts (Mendoza 1997) it is considered meteorological frost when minimum temperatures are less than 0 °C. However, it is difficult to establish the critical temperature of the crop, because the severity of the damage depends on other factors among them: the state of development of the vegetative, type of crop, soil condition, frost duration and type of soil. Some *Solanum* species such as, *S. multidisectum*, *S. chomatophilum*, *S. acaule and S. commersonii* have frost tolerance and can be used to generate tolerant genotypes (Arcos et al. 2024; Dong et al. 2023).

Frost tolerance is measured through plant damage in percentage and recovery capacity using the scales in Tables 5 and 6 (Estrada 2000), a genotype with a grad rating, for a frost of −4° C for more than an hour has good tolerance, after a frost it is recommended to apply foliar fertilizers, the main response variable is tuber yield.

Table 4 Frost damage evaluation scale. (Estrada 2000)

Grade	% of damage
1	0–10
2	11–20
3	21–30
4	31–40
5	41–50
6	51–60
7	61–70
8	71–80
9	> 80

Table 3 Tuber yield (t/ha.) in eleven adaptation and efficiency trials of the INIA 333 – CHUGAYNA variety. Growing seasons 2013-2014, 2014-2015

Locality	Growing Season	**INIA 333 -CHUGAYNA CIP386714.6**	INIA 302 -AMARILIS	Huevo de Indio	Peruanita	Bretaña	Perla
Macullida	2013-2014	36.85 b	46.69 a	20.91 c	11.99 c	10.55 d	15.18 c
San Juan Bajo	2013-2014	54.47 a	47.74 b	21.03 c	10.86 d	11.14 d	12.19 d
La Soledad	2013-2014	54.73 a	46.61 b	18.81 c	13.50 c	8.83 d	14.47 c
La Soledad	2014-2015	45.81 a	19.16 b	17.45 b			
Arcopampa	2014-2015	44.84 a	20.38 b	18.29 b			
Canucubamba	2014-2015	47.29 a	18.47 b	19.30 b			
San Francisco	2014-2015	47.87 a	21.92 b	18.30 b			
Pichauli	2014-2015	46.11 a	20.18 b	16.15 b			
El Progreso	2014-2015	46.91 a	20.62 b	18.06 b			
Nuevo Huaycho	2014-2015	48.61 a	20.62 b	18.06 b			
San Juan Alto	2014-2015	44.70 a	18.45 b	18.29 b			
Average		47.11	27.35	18.27	12.12	10.17	13.95
Standar Deviation		4.84	12.67	7.48	1.32	1.20	1.56

Means with the same letter are statistically equal (Tukey's test $P < 0.05$)

Table 5 Scale of the recovery capacity of frost damage in the potato crop

Description	Score
Very poor recovery	1
Bad recovery	3
Regular recovery	5
Good recovery	7
Very good recovery	9

Table 6 Degree of damage due to frost in La Soledad. Growing seasons 2013–2014 and 2014–2015

Varieties	2013–2014	%	2014–2015	%
INIA 333 - CHUGAYNA	2 a	11–20	2 a	11–20
INIA 302 - AMARILIS	5 b	41–50	4 b	31–40
Huevo de Indio	8 c	71–80	8 c	71–80

In the 2012–2013 growing season, in an experiment planted in San Juan Bajo, district of Chugay, province of Sánchez Carrión, in the region of La Libertad in northern Peru, frosts of −2 °C occurred, affecting the variety INIA 333-CHUGAYNA in 55% of damaged foliage (Grade 6), compared to the variety INIA 302-AMARILIS with 61.25% of foliar damage (grade 7), 18 days later the variety INIA 333-CHUGAYNA presented a good recovery capacity (grade 7), while the INIA 302-AMARILIS variety had a regular recovery capacity (Grade 5).

In Growing seasons 2013–2014 and 2014–2015, frost damage was evaluated in La Soledad (−2 °C), where the INIA 333-CHUGAYNA variety was affected from 10 to 20% of the foliage (grade 2). variety INIA 302-AMARILIS was affected up to grade 5 and Huevo de Indio with grade 8 (Table 7).

In 2016, a seed production plot of the INIA 333-CHUGAYNA variety was damaged in 62% (grade 7) by frost, due to its high recovery capacity, after 14 days the foliage was 100% recovered. Demonstrating very good tolerance to frost, compared to traditional varieties,

Late Blight Resistance

Resistance to late blight (*Phytophthora infestans*) was evaluated in all adaptation and efficiency trials to validate its level of resistance under local field conditions. The INIA 333-CHUGAYNA variety presented lower AUDPC values than the control varieties in all localities, the higher the AUDPC value, the more susceptible the variety is.

The new variety INIA 333-CHUGAYNA presented AUDPC values in the range of 20.00 in Arcopampa (2014–2015) to 608 in Canucubamba (2014–2015) with an average AUDPC of 56.00, compared to the control varieties INIA 302-AMARILIS and Huevo de Indio with average AUDPC values of 106.00 and 368.00 respectively. (Fig. 3). Demonstrating that this new variety, due to its lower AUDPC values than the control varieties, is more resistant to late blight, the main disease of potato crops in Peru and the world, corroborating its previously determined resistance under conditions of high disease pressure in Oxapampa and Comas in Peru.

The higher its value AUDPC, the more susceptible the clone or cultivars is (Forbes et al. 2014). Resistance and susceptibility are closely related, and the methods to estimate them are not based on a scale that allows a better estimate of the resistance or susceptibility means and their coefficient of variation (Yuen and Forbes 2009). There is no standard system to measure the degree of resistance to late blight in potato clones, which are generally rated as resistant, moderately resistant or susceptible. This classification can be useful, but for the comparison of genotypes in different environments it is very limited. To address this problem, Yuen and Forbes 2009 proposed a simple scale with values from 0 (Highly resistant) to 9 (Very suceptible), which can be calculated from the AUDPC values; however, to use this scale it is required to have a susceptible cultivar as a reference in all the experiments to be compared. This cultivar was the Huevo de Indio variety, which was assigned a sAUDPC value of 6 at all locations. The formula for calculating the sAUDPC is as follows:

$Sx = Sy\ (Dx/Dy)$.

where Sx is the scale value calculated for the clone under study; Sy is the scale value (6) assigned to the susceptible control cultivar Huevo de Indio, Dx is the AUDPC value of the clone under study, and Dy is the AUDPC value of the susceptible control.

The INIA 303 – CHUGAYNA variety presented sAUDPC values in the range of 0.37 in Arcopampa up to 1.20 in Pichauli, both in the 2014–2015 growing season. (Fig. 4)

Glycoalkaloid and Iron Content

Climate change is affecting weather patterns in traditional potato-growing areas, where unpredictable rainfall and higher temperatures increase pest and disease pressure and reduce tuber yields (Hijmans 2003). Another important effect is the increase in glycoalkaloid content (Levy and Veilleux 2007). High levels of glycoalkaloids can produce a bitter taste and may be hazardous for human consumption at levels above 20 mg per 100 g. fresh weight (Ruprich et al. 2009). Also a large majority of people, especially

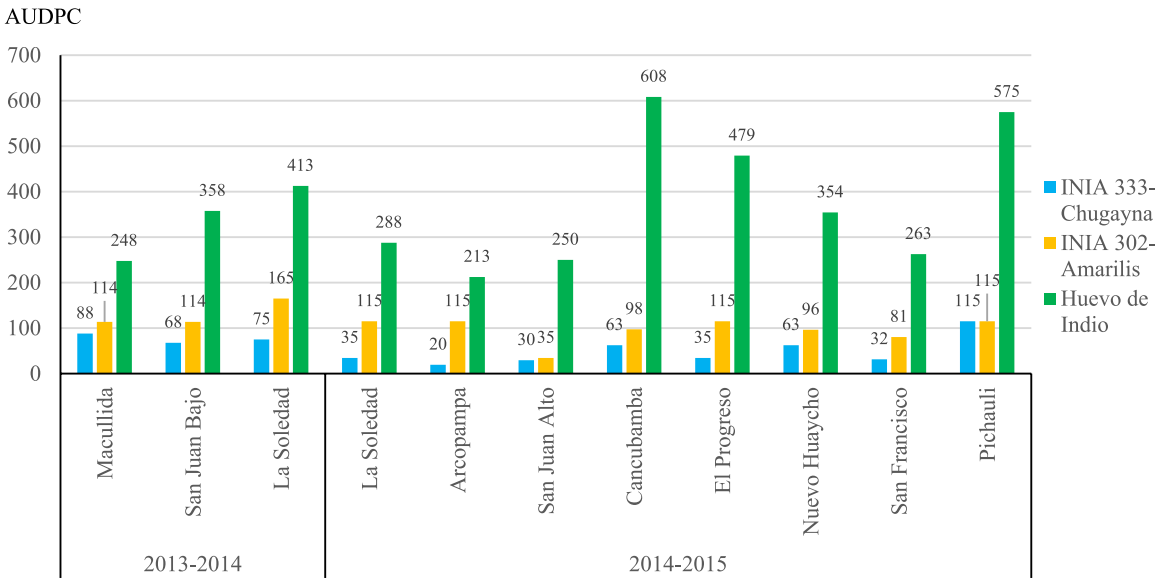

Fig. 3 Resistance to late blight (AUDPC) in eleven sites. Growing seasons 2013–2014, 2014–2015

children under 5 years of age and pregnant mothers, who live in areas where frost is a limitation in the production of potato crops, suffer from anemia and child malnutrition due to lack of consumption of products that have iron.

Taking these factors into consideration, the content of glycoalkaloids and iron was determined in samples of tubers of the variety INIA 333-CHUGAYNA, in the Quality and Nutrition laboratory of the CIP in La Molina, Lima, Peru based on samples of tubers harvested in the month of June 2019 in Chugay, Sanchez Carrion, La Libertad at 3500 m.a.s.l.

The iron content was determined in samples of 7 tubers, following the Inductively Coupled Plasma Emission Spectrometry (ICP-OES) methodology (Burgos et al. 2007) given its precision and high sensitivity for the determination of minerals in plants and food products (Boss and Fredeen 1997).

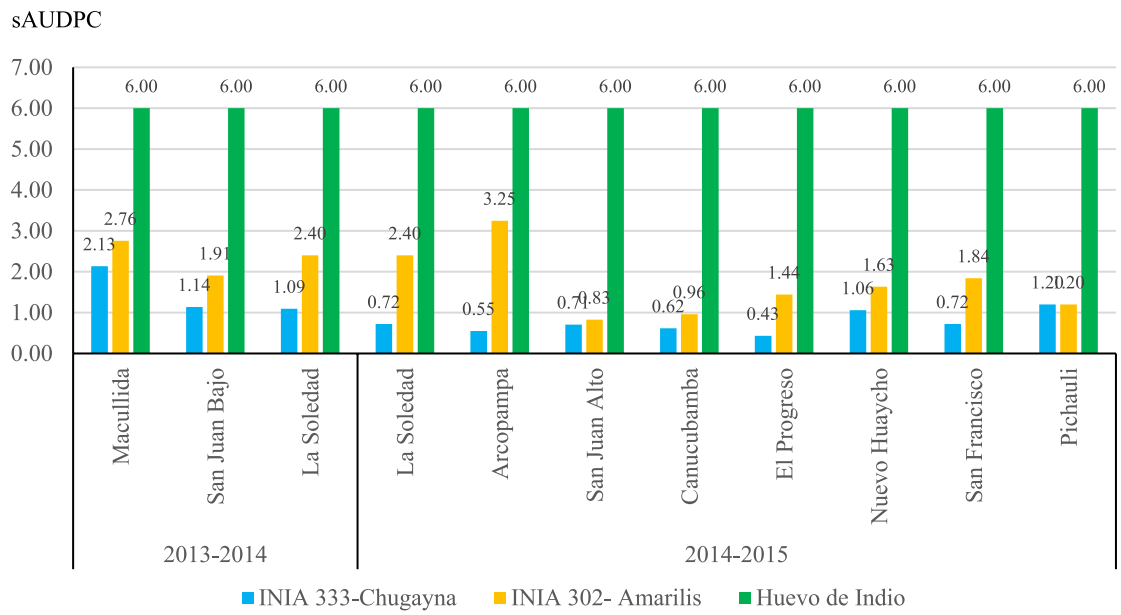

Fig. 4 Scale of resistance to late blight (sAUDPC) in eleven sites. Growing seasons 2013–2014, 2014–2015

glycoalkaloids were determined in samples of 15 tubers, which were freeze-dried and ground, stored at −20 °C until analysis. The analysis of total glycoalkaloids was performed using the method described by Burgos et al. (2014) in which the extraction of glycoalkaloids was carried out using methanol and chloroform following a concentration process at 60 °C in a rotary evaporator. The extract was transferred to 2% acetic acid solution and then purified using ammonium hydroxide at 85 °C and ultracentrifugation at 27,000 rpm. The pellet was reacted with 85% ortho phosphoric acid and read at 408 nm in a spectrophotometer.

The INIA 333-CHUGAYNA variety has an average of 18.30 mg of iron per kg of dry weight and the total glycoalkaloid content was 0.61 mg/100 g. of fresh weight, less than the maximum allowable limit. characters that would allow it to support the control of malnutrition (Anemia) and the quality of the tubers due to their low content of glycoalkaloids compared to the commercial variety INIA 202 – AMARILIS, widely planted in the area that presented low glycoalkaloid contents.

Organoleptic Quality

In the 2014–2015 growing season, the organoleptic test of appearance, flavor and texture was carried out within the participatory varietal selection methodology, with the objective of knowing the acceptance of the quality for fresh consumption of the INIA 333-CHUGAYNA variety. This test was carried out at harvest in La Soledad, San Juan Alto, Cunucubamba, El Progreso and Nuevo Huaycho. The tasting panel was made up of 10 farmers in each location, who evaluated the appearance, flavor and texture of tubers cooked for 30 min on average, according to De Haan et al. (2017) and Salas et al. (2019). The organoleptic evaluation is carried out on tuber samples that were coded, to avoid a bias in the scores given by farmers.

The information obtained from the panel of evaluators was analyzed with the Kruskal-Wallis test ($p < 0.01$) to analyze non-parametric data (Kruskal and Wallis 1952), observing significant statistical differences for appearance, flavor and texture between the three varieties evaluated. The variety INIA 333-CHUGAYNA was superior and statistically different ($p < 0.01$) from the control varieties INIA 302-AMARILIS and Huevo de Indio for appearance, flavor and texture in all locations and on average (Table 7), thus demonstrating its high quality for fresh consumption, taking into account that in the locations where the trials were carried out, the population in their daily diet consumes the control varieties due to their good culinary quality.

Table 7 Result of the organoleptic evaluation of appearance, flavor and texture in tubers of the varieties INIA 333-CHGAYNA, INIA 302-AMARILIS and Huevo De Indio in five locations. Growing season 2014–2015

Character	Varieties	Score	Signification *
Appearance	INIA 333-CHUGAYNA CIP386714.6	85.00	a
	INIA 302 - AMARILIS	42.60	b
	Huevo de Indio	46.20	b
Flavor	INIA 333-CHUGAYNA CIP386714.6	80.20	a
	INIA 302 - AMARILIS	47.00	b
	Huevo de Indio	43.40	b
Texture	INIA 333-CHUGAYNA CIP386714.6	69.80	a
	INIA 302 - AMARILIS	45.00	b
	Huevo de Indio	42.60	b
General	INIA 333-CHUGAYNA CIP386714.6	235.00	a
	INIA 302 - AMARILIS	134.60	b
	Huevo de Indio	132.20	b

Kruskal Wallis test ($p < 0.01$)

Economic Profitability

The profitability of the new variety INIA 333-CHUGAYNA was determined based on yield, production costs and farm sale price in Peru.

The economic profitability per hectare of the new variety and the control varieties was calculated for each location based on the following formulas:

$$Economic\ profitability\ (\%) = \left(\frac{Net\ income}{production\ costs}\right) \times 100$$

$$Net\ income = Total\ income - production\ costs$$

$$Total\ income = Tuber\ yield\ per\ hectare \times farm\ sale\ price$$

Table 8 Economic profitability of the new variety INIA 333-CHUGAYNA, compared to the traditional varieties INIA 302-AMARILIS and Huevo de Indio. Growing season 2014-2015

Variety	INIA 333-CHUGAYNA	INIA 302-AMARILIS	Huevo de Indio
Economic Profitability (%)	258.49	61.26	92.5

The sale price on the farm was from US$ 0.18 to US$ 0.26 per kg, for the new variety and CIP 302-AMARILIS, for the Huevo de Indio variety the sale price on the farm varied from US$ 0.34 to US$ 0.40 /kg, this variety has a better price for being a native variety and in Peru depending on the location, these have a higher price than improved varieties. The final economic profitability was obtained by averaging the profitability of each location.

The new variety INIA 333-CHUGAYNA has a profitability 4 times more than the variety INIA 302-AMARILIS and 3 times more than the native variety Huevo de Indio (Table 8). A factor that has influenced achieving this high profitability is the yield of tubers under low temperature conditions in the locations where the adaptation and efficiency trials were carried out.

Conclusions

- The INIA 333-CHUGAYNA variety has been released as a new potato variety resilient to climate change with tolerance to frost, resistance to late blight, good quality for fresh consumption, high yield of tubers and high economic profitability, superior to traditional varieties that were used as controls, INIA 302-AMARILIS and Huevo de Indio. This new variety has been registered in the national registry of commercial varieties of Peru: Registry N° 001–2022-MIDAGRI-SENASA-CAJAMARCA.
- This new variety would easily adapt to the family farming system for the benefit of small and medium producers, improving their quality of life,| especially those who grow potatoes in the high Andean areas where one of the main abiotic problems is the presence of frost, due to the prevailing low temperatures.
- The seed of this variety is available from INIA, the NGO Asociación Pataz, which produces and sells certified seed, and the CIP maintains the in vitro plants in its germplasm bank.

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Declarations

Conflict of Interest The authors declare no competing interests.

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