Impact of initial explants on in vitro propagation of native potato (*Solanum tuberosum*, Andigena group)

Lenny Yojana Correa Mora¹,² · Daicy Yaneth Galvis Tarazona¹ · María de los Angeles Bohórquez Quintero¹ · Eyda Johanna Araque Barrera¹ · Johan Sebastian Urquijo Ruíz³ · Diana Marcela Arias Moreno¹ · Zaida Zarely Ojeda Pérez¹

Received: 24 February 2022 / Accepted: 24 April 2022 / Published online: 22 May 2022
© The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract
The high nutritional potential of native potatoes makes them an invaluable genetic resource for breeding. However, pathogens have caused both yield and industrial quality losses, and plant tissue culture is a promising alternative to obtain clean plant material. We compared distinct segments excised from apical and lateral sprouts taken from tubers as initial explants for in vitro culture of sixteen native potato genotypes. Thus, apical-distal (AD), mid-apical, lateral-distal, and mid-lateral segments were all grown on Murashige & Skoog medium. These explants were aseptic, reactive, and viable for all genotypes (with a probability greater than 30%), yielding cumulative proliferation rates of up to 1:10 individualizable segments, and about 86% of in vitro plants with 2 to 11 roots of up to 117 mm long. Responses were genotype-dependent during all stages of cultivation, and the best responding genotypes were Maravillosa, Duraznillo and Pepina Rodeo. On the other hand, AD sprouts were the best sprout type and segment for in vitro establishment, regardless of genotype. This is the first study of its kind with such a large range of Andean potato genotypes and should contribute to their germplasm conservation and increased multiplication efficiency.

Key message
Distal segments of apical sprouts gave the best in vitro morphogenic responses for sixteen different Andean native potato genotypes.

Keywords Native potato · Micropropagation · Morphogenic potential · Germplasm conservation

Introduction
*Solanum tuberosum* (potato) is one of the most important crops in the world, being widely distributed in five continents: Africa, Asia, Oceania, Europe, and the Americas. This vegetable resource serves a major role in agriculture, economy, food security, and poverty eradication (Bradshaw and Ramsay 2009; Bradeen and Haynes 2011; Calliope et al. 2018). Grown potatoes have a large gene pool and include both native and improved varieties (Machida 2015). However, its production and commercialization are centered on a few genotypes, most of which have been agronomically improved, derived from wild and native materials (Fock et al. 2000; Berdugo-Cely et al. 2017).

Native potatoes are the result of a long-term selection and diversification process from their origin in the Lake Titicaca basin on the Peru-Bolivia border (Hardigan et al. 2017). These...
are the oldest domesticated tubers in the Andes and it have a wide range of sizes, shapes, and colors (Tinjacá and Rodríguez 2015). Diversity is conserved in rural communities for subsistence use and as a highly valued heritage. Some of these genotypes are considered superfoods because of their large quantity and quality of nutrients and functional compounds (Calliope et al. 2018).

These tubers provide a rich, unique and diverse source of genetic variation (Tejeda et al. 2020). They adapt to different environmental conditions and are highly tolerant to drought, frost, subfertile soils, plagues and diseases (Calliope et al. 2018). In the present context of climate change, native genotypes constitute an innovative alternative in favor of global food security (Lizana et al. 2021), and their study would allow the identification of “elite germplasm” for the development of breeding programs in target varieties (Calliope et al. 2018).

Around 400 native materials have been registered in Colombia and that are cultivated mainly in the departments of Nariño, Cundinamarca and Boyacá (Moreno and Valbuena 2006; Tinjacá and Rodríguez 2015). However, production systems of native potato face a lack of certified seed, technologies, and tools to strengthen its production, as well as changing market demands and high commercial competition. These limitations have influenced the cultural detriment of these potatoes and incur their possible extinction. Therefore, it is necessary to implement methods of propagation and conservation of these resources to foster their use genetic and agro-industrial use in order to increase the income of peasant farmers of the Altiplano (Tapia and Fries 2007).

Plant tissue culture has been used extensively as a successful strategy for the propagation of commercial potato varieties, and its deployment in native genotypes is a promising approach. Thus, micropropagation combined with crop diagnosis and sanitation, contributes to the conservation of native potato cultivars, the production of clean plant material, seed production, and genetic improvement programs (Agramonte 1999; Igarza et al. 2012; Valderrama et al. 2018). However, standardizing of efficient in vitro propagation protocols has been complex due to the strong correlation of genotype-dependent responses, physiological and phytochemical conditions of the mother plant (Naik and Buck Seth 2018), as also the selected explant type, the applied surface disinfection treatment, and the physicochemical culture conditions (Mohapatra and Batra 2017). Here, we evaluated for the first time the effect of four types of initial explants on in vitro culture of a wide range of native potato genotypes.

Materials and methods

The research was carried out at the BIOLASMA Plant Tissue Culture Laboratory, Universidad Pedagógica y Tecnológica de Colombia (UPTC). The initial plant material consisted of seed tubers from sixteen native potato genotypes (Solanum tuberosum, Andigena group) cultivated in the Boyacá department in Colombia. The native genotypes are: Aguacata (Ag), Alcarrosa (Al), Amapola (Am), Balbanera (Ba), Chaucha Botella (Cb), Duraznillo (Du), Macachona (Ma), Manzana (Mnz), Maravillosa (Mar), Mortiña Azul (Maz), Pacha Negra (Pn), Pepina Rodeo (Pr), Rastrella (Ra), Ratona Morada (Rm), Tornilla Crema (Tc) and Yema de Huevo (Yhl). For each genotype, fifteen tubers of similar sizes were randomly selected and stored until sprouting under dark conditions, with an average temperature of 17 °C and a vapor pressure deficit of 0.7.

In vitro establishment

Apical and lateral sprouts (2 to 3 cm long) were excised from the tubers and the distal and middle 1–2 cm long segments with at least one developing bud were isolated. For each genotype, 32 explants were isolated and uniformly distributed in four categories according to the sprouting type (Apical or Lateral), and segment position within the sprout (Mid or Distal), into the four categories: Apical-Distal (AD), Mid-Apical (MA), Lateral-Distal (LD), and Mid-Lateral (ML). Thus, we examined whether the type or origin of the cultured explant had any effect on the genotype’s response to in vitro culture.

After isolation, the explants were (i) washed with tap water for 30 min prior to surface disinfection under a laminar flow hood; (ii) rinsed with sterile distilled water (SDW) + Tween® 20 (polysorbate) for 10 min; (iii) immersed in EtOH (30% v/v) for 45 s; (iv) rinsed again with SDW; (v) immersed in 3% (v/v) sodium hypochlorite (5.25% w/v NaClO) for 10 min; and finally (vi) rinsed 5 times with SDW. The disinfected portions were placed in 10 ml glass containers with 3.5 ml of MS (Murashige and Skoog 1962) basal culture medium. The asepsis, reactivity, and viability of explants were evaluated every 5 days until day 25. To evaluate the effect of the explant on the in vitro culture response throughout all the stages, the traceability of the initial explant (AD, MA, LD or ML) origin was maintained.

Sprout multiplication

Apical portions (1–2 cm long) with at least one bud were excised from these established explants. For each category (AD, MA, LD, and ML), between 1 and 9 such portions were cultured in glass containers with 15 ml of MS medium (subculture #1), and subcultured monthly (#1, #2 and #3) for multiplication. At each subculture, the thickness of the main stem (thin: < 1 mm and thick: > 1 mm), the total length of the explant (mm), the number of secondary stems, number of
nodal segments (NS), and the cumulative proliferation rate (PR) were recorded.

For each genotype, the number of nodal segments (NS) (shoot of ~ 1.5 cm with at least one bud) in each subculture was calculated as \( NS = S_o - S_c \), where \( S_o \) = obtained nodal segments and \( S_c \) = nodal segments initially cultured. Additionally, the relationship between the number of nodal segments (NS) per nodal segment initially cultured \( (S_c) \) was determined to know the cumulative proliferation rate (PR).

**Sprout rooting**

From the plant material obtained in multiplication, 4–6 apical segments (1–2 cm long and with at least one bud) of each category (AD, MA, LD, and ML) were grown on MS medium. The presence of the main root, secondary roots, and adventitious roots was evaluated after 20 days of culture. In addition, the root number and the total root length (mm) per explant were determined.

**Growing conditions**

The pH for all culture media was adjusted to 5.7 prior to autoclaving at 15 psi and 121 °C for 20 min. The cultured explants were incubated at 24 ± 1 °C with continuous light (70–80 μmol m\(^{-2}\) s\(^{-1}\)) supplied by 75 W fluorescent lamps.

**Statistical analysis**

Asepsis, reactivity, viability, stem thickness, main root formation, secondary roots, and adventitious roots values were analyzed by binomial logistic regression using PROC LOGISTIC the statement. A two-way variance analysis (ANOVA) of total explant length and root length was performed using PROC GLM. The number of secondary stems, the number of nodal segments (NS), and the number of roots was analyzed with a generalized linear model using a Poisson distribution as a link function using PROC GENMOD. For ANOVA and generalized linear model, once significance was tested, Tukey’s adjusted least-squares mean comparisons were performed. These analyses were performed using SAS University Edition Software (SAS Institute Inc. 2019) with a confidence level of 95%.

**Results**

**Genotype, sprout, and sprout segment determined the asepsis, reactivity, and viability of explants**

We evaluated the effects of four different initial explants (AD, MA, LD, and ML) on the in vitro establishment of native potato genotypes during 25 days (Figs. S1–3). The distal segments provided the highest number of aseptic explants (probability greater than 50%) in 75% of the genotypes studied (Fig. 1). All types of explants evaluated permitted to establish aseptic cultures in vitro. However, the differential response was influenced by time of culture the genotype and sprout segment \( (p > 0.001) \) (Table S1). The highest rates of reactivity \( (R: p > 0.0001) \) and viability \( (V: p > 0.0070) \) were observed with AD segments, where 70% of genotypes gave values higher than 60% (Fig. 1, Table S1). AD segments from \( Mnz, Pn, Du, Tc, Yh, Pr \) and \( Rm \) genotypes yielded the greatest number of aseptic in vitro plants (Figs. 1, 2). Additionally, it was interesting to observe that the use of 30% ethanol favored a better response for in vitro culture (Table S2).

**Sprout multiplication was influenced by genotype**

In order to determine the effect of the four different types of initial explant on sprout multiplication we recorded the thickness of the main stem, the explant length, and the number of secondary stems and of nodal segments for all the native potato genotypes (Tables S3–S5). For all genotypes, it was possible to multiply the material by clonal culture of nodal segments, with between 2 and 6 segments individualized per subculture and genotype (Fig. 3). In terms of the number of nodal segments, the genotype was statistically significant \( (p < 0.0001) \) (Table S6). In fact, the genotype was the only factor that influenced the response of each native potato studied. Additionally, to define the cumulative proliferation rates for each genotype we evaluated the number of the nodal segments during 90 days. We found that the cumulative proliferation rates were from 1:5 to 1:10 segments per explant, and that \( Pr, Mar \) and \( Rm \) were the genotypes with the highest cumulative proliferation rates (Fig. 4).

**AD and ML were the best explants in terms of rhizogenic response**

We evaluated the rhizogenic response of the different explant types through the presence of main, secondary, and adventitious roots and number and total length of roots after 20 days of culture (Tables S7–S9). About 86% of shoots rooted for all initial explants tested. However, the highest roots number (2 to 11) and the longest roots (up to 117 mm) were obtained from AD and ML explants (Fig. 5). The genotype \( (p < 0.0001) \) and sprout segment \( (p = 0.0138) \) were the only factors that influenced rhizogenic responses (Tables S8–S9). \( Du, Ma, Mar \) and \( Mnz \) were the genotypes with the best rooting responses using AD and ML initial explants.
During the different stages of in vitro culture, a better morphophysiological response was observed with the AD explant in genotypes Mar, Pn, Pr and Rm, which also showed the best regenerative capacity and establishment.
of aseptic in vitro plants with high proliferation rates (Table S10 and Fig. S4).

Discussion

The ontogenic characteristics of the plant, and the physiological state and position of the shoots with respect to the apex can significantly influence the morphophysiological response of explants in vitro (Aguilar et al. 1992; Chanatásig 2004). Therefore, it was relevant to know the impact of the initial explant such as AD, MA, LD, and ML on the in vitro response of this native potato genotypes, not yet studied.

Our work allows to fill the knowledge gap regarding the in vitro response of native genotypes during all phases of micropropagation, since most of the studies mainly report results for commercial varieties in some stages of the process. The results highlight the need for an adequate selection of the initial explant type, as this was a determining factor both to obtain a high percentage of aseptic, reactive, and viable cultures, as well as for the regeneration and growth of sprouts and roots throughout the in vitro culture stages evaluated.

In the establishment stage, the AD segments allowed the recovery of a greater quantity of plantlets, with a viability even higher than reported by Badoni and Chauhan (2010), Fawzia et al. (2015) and Shahriyar et al. (2015). The results of these investigations are comparable with ours because they evaluated the in vitro establishment of potato, however they did not study the impact of the initial explant in neither of the micropropagation stages. The response observed in our study can be attributed to the presence in the AD explant of the shoot apical meristem (SAM), whose morphogenic activity allows continuous and rapid cell division, and leads to the fast formation and growth of in vitro plants (Rzepka-Plevnes et al. 2009; Huamán et al. 2012). Furthermore, the gibberellins content in the SAM would favor cell differentiation, longitudinal growth and cytoskeletal rearrangement (Gao et al. 2017), while auxins would allow the initiation of lateral organs and roots (Ha et al. 2010).

Likewise, the high percentages of asepsis observed in this study were also influenced by the presence of the SAM. The high metabolic activity in these tissue influences the
non-uniform distribution of microorganisms in plants, with a progressive reduction from the base towards the apex of the stem (Hernández and González 2010). Although high asepsis was obtained, it must be noted that the number of aseptic explants decreased with time in culture. This could be attributed to the occurrence of endogenous microbial contamination and/or to the production and accumulation of phytotoxins, which can cause tissue necrosis and a consequent decrease in reactivity and viability of the explants (Slavov 2005; Tekielska et al. 2019).

On the other hand, we observed that for all genotypes, a high proliferation rate and a large number of vigorous plants were obtained. Furthermore, the evaluated genotypes showed development characteristics superior to those reported for other potato cultivars and varieties (García-Águila et al. 2015; Tacoronte et al. 2017; Araque Barrera et al. 2018; Valderrama et al. 2018; Xhulaj and Gixhari 2018), which could be attributed to a genotype-dependent response.

In terms of rooting, this research confirmed that the endogenous hormone concentrations (mainly auxins in the SAM) of native genotypes ensure root growth and development without the addition of external inducers (Ha et al. 2010). In our study, 100% of the evaluated in vitro plants showed some rhizogenic response, highlighting a high number of roots in explants derived from AD segments. The

Fig. 3 Identifiable nodal segments in three subcultures per genotype and initial explant type: Apical-Distal (AD), Mid-Apical (MA), Lateral-Distal (LD), and Mid-Lateral (ML). Different letters between genotypes indicate statistically significant differences, according to the least significant difference (LSD) multiple comparison test (p ≤ 0.05). Ag Aguacata, Al Alcarrosa, Am Amapola, Cb Chaucha Botella, Du Duraznillo, Ma Macachona, Mnz Manzana, Mar Maravillosa, Mz Mortiña Azul, Pn Pacha Negra, Pr Pepina Rodeo, Ra Ras trera, Rm Ratona Morada, Tc Tornilla Crema and Yh Yema de Huevo
formation of the in vitro root system influences anchorage to the substrate and water absorption when plants are established ex vitro, and therefore, it can improve their survival in the acclimatization stage (Arellano et al. 2010; Mukul and Ginzberg 2020).

A differential in vitro response between genotypes was apparent in this study, as also previously reported by Mroginski et al. (2010), Naik and Buckseth (2018) and Singh (2018). Some genotypes such as *Mar*, *Pn*, *Pr* and *Rm* showed a differential response capacity during the propagation stage similar or even superior to commercial varieties, which would allow the identification of “elite germplasm” to be used as parents in future breeding programs (Calliope et al. 2018). Likewise, the genetic improvement of plants together with new technologies (e.g., haploid and double haploid) would allow obtaining crops with high productive potential and desired agronomic traits with enormous benefits to the local producer and consumer (Núñez-Zarantes 2020).

This research reports, for the first time, the impact of the initial explant on the efficient propagation of native potato genotypes. Our results show the relevance of the adequate selection of the initial explant (AD) from the beginning of the process to guarantee a large number of plantlets, with high multiplication rates and rhizogenic capacity. This work constitutes a useful tool for the establishment of in vitro germplasm banks and micropropagation systems extrapolatable to other cultivars and/or potato varieties with food relevance. Thus, our results provide a reliable method to obtain plants of high genetic, morphological, and phytosanitary quality at any time of the year, thereby decreasing operating and production costs.

It is expected that this research will promote studies towards the industrial use and conservation of native potatoes cultivated in Colombia. In this way, the use of these forgotten genetic resources will be able to contribute to the food security under the current changing climatic conditions. As well as with the preservation of traditional cuisine, the creation of new gastronomic trends and their cultural and traditional value will be highlighted. Additionally, this study underlines the need to deepen the multidisciplinary research of local genotypes, with a view
to granting and dignifying the potential of these Andean tubers, which are part of the cultural and agronomic heritage of South America.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11240-022-02317-1.

Acknowledgements The authors thank the Ministry of Science, Technology and Innovation of Colombia, the Government of Boyacá, Boyacá and Colombia Bio Program, the Universidad Pedagógica y Tecnológica de Colombia (UPTC), the Vice-rectory for Research and Extension of UPTC and the Young Researcher Program of the UPTC, the Mayor’s Office of the municipality of Chiscas, and the company Tesoros Nativos SAS, for financing and support during the development of the research. Additionally, the authors thank the BIO-PLASMA-UPTC research group.

Fig. 5 Root development in potato explants for each genotype and per type of initial explant: Apical-Distal (AD), Mid-Apical (MA), Lateral-Distal (LD), and Mid-Lateral (ML). As the number of roots increases, the size of the geometric shapes becomes larger. In the legend on the right, for example, the size of the spheres represents the number of roots developed for the AD category. This same range is applicable for the LD, MA and ML categories represented by triangle, square and diamond, respectively. Ag Aguacata, Al Alcarrosa, Am Amapola, Cb Chaucha Botella, Du Duraznillo, Ma Macachona, Mnz Manzana, Mar Maravillosa, Maz Mortiña Azul, Pn Pacha Negra, Pr Pepina Rodeo, Ra Rastrera, Rm Ratona Morada, Tc Tornilla Crema and Yh Yema de Huevo. Initial explants that are not represented for some of the genotypes were not grown at the rooting stage.

Author contributions LC, DG, MB EA, JU, DA and ZO contributed to the study conception and design; JU analyzed the data; LC, DG, MB, and EA interpreted the data and wrote the manuscript with contributions of all authors. All authors read and approved the final manuscript.

Funding The research leading to these results received funding from the Boyacá and Colombia Bio Program, convocation 794 of 2017 I+D projects for the technological development of a biological origin that contribute to the challenges of the Department of Boyacá-2017. Also, partial financial support was received from by Young Researcher Program 2020 of the UPTC, convocation VIE No. 18.

Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.
Declarations

Conflict of interest The authors have no conflict of interest.

Consent to participate Not applicable.

Consent for publication Not applicable.

Ethical approval Not applicable.

Research involved in humans and animals Not applicable.

References

Agramonte D (1999) Métodos biotecnológicos para la producción de semilla original de papa (Solanum tuberosum L.). Instituto de Biotecnología de las Plantas, Cuba

Aguilier ME, Villalobos VM, Vásquez N (1992) Production of cocoa plants (Theobroma cacao L.) via micrografting of somatic embryos. Vit Cell Dev Biol Plant 28P:15–19

Araque Barrera EJ, Pacheco Díaz JE et al (2018) Propagación y tuberización en vitro de dos variedades de papa. Cienc en Desarrollo 9:21–31. https://doi.org/10.19053/01217488.v9n1.2018.7132

Arellano M, García M, Villavicencio E, García S (2010) Propagación y producción de plantas y semilla prebásica de variedades comerciales de papa libres de enfermedades, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro de Investigación Regional Noreste, 1st edn. Campo Experimental Saltillo, Saltillo

Badoni A, Chauhan JS (2010) In vitro sterilization protocol for micropropagation of Solanum tuberosum cv. ‘Kufri Himalini.’ Acad Arena 2:24–27

Berdugo-Cely J, Valbuena RI, Sánchez-Betancourt E et al (2017) Genetic diversity and association mapping in the colombian central collection of Solanum tuberosum L. Andigenum group using SNPs markers. PLoS ONE 12:e0173039. https://doi.org/10.1371/journal.pone.0173039

Bradeen J, Haynes K (2011) Introduction to potato. In: James M (ed) Genetics genomics and breeding potato. CRC Press, Boca Raton, pp 6–14

Bradhaw J, Ramsay G (2009) Potato origin and production. Advances in potato chemistry and technology, 1st edn. Elsevier Ltd, Amsterdam, pp 1–26

Calliope S, Oscar M, Sammán N (2018) Biodiversity of andean potatoes: morphological, nutritional and functional characterization. Food Chem 238:42–50. https://doi.org/10.1016/j.foodchem.2016.12.074

Chatanásig C (2004) Inducción de la embriogénesis somática en clones superiores de cacao (Theobroma cacao L.), con resistencia a enfermedades fungosas, Centro Agronómico Tropical de Investigación y Enseñanza CATIE, Cartago

Fawzia E, Marwa E, El-kazzaz AA (2015) Micropropagation of four potato cultivars in vitro. Acad J Agric Res 3:184–188. https://doi.org/10.15413/ajar.2015.0145

Fock I, Collonniere C, Purwito A et al (2000) Resistance to bacterial wilt in somatic hybrids between Solanum tuberosum and Solanum phureja. Plant Sci 160:165–176. https://doi.org/10.1016/S0168-9452(00)00375-7

Gao X, Zhang Y, He Z, Fu X (2017) Gibberellins. In: Li J, Li C, Smith SM (eds) Hormone metabolism and signaling in plants. Academic Press, London, pp 107–160

García-Águila L, Rodríguez M, La OM et al (2015) Propagación in vitro de variedades cubanas de Solanum tuberosum L. ‘yuya’, ‘marinca’, ‘grettel’ e ‘ibis’. Biotecnol Veg 15:75–83

Ha CM, Jun JH, Fletcher JC (2010) Shoot apical meristem form and function. Curr Top Dev Biol 91:103–140

Hardigan MA, Laimbeer FPE, Newton L et al (2017) Genome diversity of tuber-bearing Solanum uncovers complex evolutionary history and targets of domestication in the cultivated potato. Proc Natl Acad Sci USA 114:E9999–E10008. https://doi.org/10.1073/pnas.1714380114

Hernández Y, González M (2010) Efectos de la contaminación y oxidación fenólica en el establecimiento in vitro de frutales perennes. Cultiv Trop 31(4):00–00

Huamán X, Ruiz-Sánchez ME, Guerrero-Abad JC et al (2012) Propagación in vitro de segmentos nodales de cedro (Cedrela odorata L.) obtenidos a partir de semillas botánicas. Folia Amaz 21:109. https://doi.org/10.24841/fva.2011i-2.39

Igarza J, Agramonte D, Alvarado Y et al (2012) Empleo de métodos biotecnológicos en la producción de semilla de papa. Biotecnol Veg 21:3–24

Lizana C, Sandaña P, Behn A et al (2021) Potato. In: Sadras VO, Calderini DF (eds) Crop physiology case histories for major crops. Academic Press, London, pp 550–587

Machida R (2015) Diversity of potato genetic resources. Breed Sci 65:26–40. https://doi.org/10.1270/jsbbs.65.26

Mohapatra PP, Batra VK (2017) Tissue culture of potato (Solanum tuberosum L.); a review. Int J Curr Microbiol Appl Sci 6:489–495

Moreno JO, Valbuena L (2006) Colección colombiana de papa: riqueza fenotípica de la variedad ‘Kufri Himalini.’ Acad J Agric Res 3:184–188. https://doi.org/10.1016/j.foodchem.2016.12.074

Núñez-Zarantes VM (2020) La tecnología doble haploide en el mejoramiento genético de frutas exóticas: uchuva, Physalis peruviana L., como estudio de caso. Rev Colom Biotecnol 22:2–5. https://doi.org/10.15446/rev.colomb.biote.v22n1.88590

Rzepka-Plevnes D, Kulpa D, Wajda A (2009) Initiation of in vitro culture for quality potato seed production. In: Gosal S, Wani SM (eds) Biotechnologies of crop improvement. Springer, Cham, pp 131–158

Núñez-Zarantes VM (2020) La tecnología doble haploide en el mejoramiento genético de frutas exóticas: uchuva, Physalis peruviana L., como estudio de caso. Rev Colom Biotecnol 22:2–5. https://doi.org/10.15446/rev.colomb.biote.v22n1.88590

SAS Institute Inc (2019) SAS University edition virtual application. SAS Institute Inc, Cary

Shahriyar S, Akram S, Khan K et al (2015) In vitro plant regeneration via somatic embryogenesis of four potato cultivars in vitro. Acad J Agric Res 3:184–188. https://doi.org/10.15413/ajar.2015.0145

Singh CR (2018) Review on problems and its remedy in plant tissue culture. Asian J Biol Sci 11:165–172. https://doi.org/10.3923/ajbs.2018.165.172

Slavov S (2005) Phytotoxins and in vitro screening for improved disinfection of potato tissue cultures. Physiol Plant 15:473–497

Acad Sci USA 114:E9999–E10008. https://doi.org/10.1073/pnas.1714380114

MO (2015) Diversity of potato genetic resources. Breed Sci 65:26–40. https://doi.org/10.1270/jsbbs.65.26

Shahriyar S, Akram S, Khan K et al (2015) In vitro plant regeneration via somatic embryogenesis of four potato cultivars in vitro. Acad J Agric Res 3:184–188. https://doi.org/10.15413/ajar.2015.0145

Singh CR (2018) Review on problems and its remedy in plant tissue culture. Asian J Biol Sci 11:165–172. https://doi.org/10.3923/ajbs.2018.165.172

Slavov S (2005) Phytotoxins and in vitro screening for improved disinfection of potato tissue cultures. Physiol Plant 15:473–497

Acad Sci USA 114:E9999–E10008. https://doi.org/10.1073/pnas.1714380114

Taconcote M, Vielman M, Olivo A, Chacín N (2017) Efectos de nitratos y sacarosa en la propagación in vitro de tres variedades de papa nativa. Rev Colomb Biotecnol. https://doi.org/10.15446/rev.colomb.biote.v19n2.70160
Tapia M, Fries A (2007) Origen de las plantas cultivadas en los Andes. Guía de campo de los cultivos andinos. Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO) y Asociación Nacional de Productores Ecológicos del Perú (ANPE), Lima, pp 1–7

Tejeda L, Mollinedo P, Aliaga-Rossel E, Peñarrieta JM (2020) Antioxidants and nutritional composition of 52 cultivars of native Andean potatoes. Potato Res 63:579–588. https://doi.org/10.1007/s11540-020-09458-w

Tekielska D, Peňázová E, Kovács T et al (2019) Bacterial contamination of plant in vitro cultures in commercial production detected by high-throughput amplicon sequencing. Acta Univ Agric Silvic Mendelianae Brun 67:1005–1014. https://doi.org/10.11118/actaun201967041005

Tinjacá S. Rodríguez L (2015) Catálogo de papas nativas de Nariño. Universidad Nacional De Colombia, Bogota

Valderrama A, Abril V, Reyes J et al (2018) Propagación clonal in vitro de especies y variedades de papa (Solanum spp.) en función del tiempo. Big Bang 7:4–8

Xhulaj D, Gixhari B (2018) In vitro micropropagation of potato (Solanum tuberosum L.) cultivars. Agric For 64:105–112. https://doi.org/10.17707/AgricultForest.64.4.12

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.