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Original Article

In vitro propagation of two promising genotypes of *Plukenetia volubilis* L.

Propagación *in vitro* de dos genotipos promisorios de *Plukenetia volubilis* L.

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Siembra 13 (1) (2026): e8021
DOI: 10.29166/siembra.v13i1.8021

Received: 14/03/2025
Revised: 27/06/2025 / 01/10/2025 / 09/12/2025
Acepted: 26/05/2026

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SIEMBRA
https://revistadigital.uce.edu.ec/index.php/SIEMBRA
ISSN-e: 2477-8850
Frequency: half-yearly
vol. 13, issue 1, 2026
siembra.fag@uce.edu.ec

Abstract

This study was conducted to determine the optimal balance of the auxins 1-naphthaleneacetic acid [NAA] and indole-3-butyric acid [IBA] for the induction of adventitious roots in nodal segments of sacha inchi (*Plukenetia volubilis* L.). Zygotic embryos from two promising sacha inchi genotypes, "Pinto Recodo" and "Mushquiyacu," were cultured on a germination medium. Subsequently, after 90 days of in vitro culture, the resulting plantlets were sectioned to obtain nodal segments containing one to two axillary buds, which were then transferred to rooting media supplemented with the growth regulators NAA and IBA. The highest percentage of adventitious root induction was achieved when IBA alone at 1 mg L^{-1} was used. The greatest root length was recorded when IBA at 1.0 and 2.0 mg L^{-1} was applied in the medium for the "Mushquiyacu" genotype, whereas in the "Pinto Recodo" genotype, this response was observed only with 1.0 mg L^{-1} IBA. The combination of NAA and IBA was not effective in either sacha inchi genotype. The use of the commercial substrate Premix during plantlet acclimatization proved to be suitable for the survival of both promising sacha inchi genotypes during the nursery stage and after transplantation to the field.

Keywords: acclimation, germination, *Plukenetia volubilis*, rooting, zygotic embryo.

Resumen

La presente investigación se realizó para determinar el balance adecuado de las auxinas ácido 1-naftalenacético [ANA] y ácido indol-3-butírico [AIB] en la inducción de raíces adventicias de segmentos nodales de sacha inchi (*P. volubilis* L.). Embriones cigóticos de dos genotipos promisorios de sacha inchi "Pinto Recodo" y "Mushquiyacu" fueron colocados en medio de germinación, posteriormente a los 90 días de cultivo *in vitro* las plántulas obtenidas se seccionaron para la obtención de los segmentos nodales con 1 a 2 yemas axilares, las cuales fueron colocados en medios de enraizamiento con reguladores de crecimiento ANA y AIB. El mayor porcentaje de inducción de raíces adventicias se logró cuando se empleó solo AIB 1 mg L^{-1}. La mayor longitud de raíces se registró cuando se empleó AIB en el medio 1,0 y 2,0 mg L^{-1} en el genotipo "Mushquiyacu", en el genotipo "Pinto Recodo" sólo cuando se empleó 1,0 mg L^{-1} de AIB. La combinación de ANA y AIB no fue efectivo en los genotipos de sacha inchi. El empleo del sustrato comercial Premix para la aclimatación de las plántulas fue el adecuado en la supervivencia de los dos genotipos promisorios de sacha inchi en la etapa de vivero y campo definitivo.

Palabras claves: aclimatación, embrión cigótico, enraizamiento, germinación, *Plukenetia volubilis*.

1. Introduction

Sacha inchi (*P. volubilis* L.) is a semi-woody, perennial climbing plant of the Euphorbiaceae family (Gillespie, 1993), found in the northwestern regions and along the Amazon River in Suriname, Venezuela, Colombia, Ecuador, Peru, Bolivia, and Brazil (Wang et al., 2018).

In Peru, sacha inchi is cultivated in the regions of Madre de Dios, Huánuco, Oxapampa, San Martín, Rodríguez de Mendoza, Ucayali, Putumayo, Iquitos, and Caballo Cocha. This species grows at elevations ranging from 100 to 1,500 m a.s.l., occurring naturally on the edges of secondary forests (Purmas), in sugarcane fields, along hedgerows, in the undergrowth of banana plantations, and in permanent crops. In the northeastern parts of the country, sacha inchi grows naturally in the San Martín region, specifically in the Huallaga River basin as far as Yurimaguas, in the Upper and Lower Mayo regions, in the Sisa Valley, and in areas of the Lamas, Shanusi, and Pongo de Caynarachi basins (Valles, 1990). In the Amazonas region, sacha inchi grows naturally at elevations between 1,100 and 1,400 meters above sea level in the province of Rodríguez de Mendoza (Millones & Vásquez, 2008). In recent years, there has been growing interest in sacha inchi due to its oilseed, which is characterized by high levels of omega-3, omega-6, and omega-9 fatty acids, high-quality proteins, and bioactive compounds with significant nutritional health benefits (Kim & Joo, 2019; Istiandari & Faizal, 2025).

Sacha inchi is propagated primarily by seed sexually and asexually using conventional methods such as cuttings; however, this method has limitations, such as the transmission of pests and diseases, and the poor induction of adventitious roots, which makes it difficult to obtain healthy and vigorous seedlings for use in the final field. Consequently, to improve rooting of cuttings, there are reports of the use of growth regulators, particularly the auxin indole-3-butyric acid [IBA] at concentrations of 2,000 ppm (Ruiz-Solsol & Mesén, 2010; Solis et al., 2019).

Plant biotechnology, through the technique of *in vitro* plant tissue culture, serves as an important tool in the micropropagation of many economically important species, providing a viable solution for the production of genetically uniform seedlings that are free of pests and diseases and possess the agronomic characteristics of selected genotypes of agronomic interest (Kim & Joo, 2019). This biotechnological technique has been applied to sacha inchi, with reports on the in vitro germination and multiplication of nodal segments (Millones & Vásquez, 2008; Henao Ramírez et al., 2021), organogenesis (Restrepo-Osorio et al., 2020), and meristems (Solis et al., 2018). The genus *Plukenetia* is characterized by the fact that several of its species have a reproductive system involving cross-pollination (allogamous), such as those reported in *P. conophora* (Agbo et al., 2015), P. *corniculata* (Feng et al., 2025), and *P. volubilis* (Valente et al., 2017). The use of these biotechnological techniques in sacha inchi is important because it is a potentially allogamous species; propagating it through seed has drawbacks because its offspring are heterogeneous. Therefore, asexual propagation is important for conserving traits of agronomic and commercial importance. Furthermore, micropropagation is a good alternative for producing clones in large quantities, in less time, free of pests and diseases, and year-round.

Taking this background into account, the present study determined the optimal balance of the auxins 1-naphthaleneacetic acid [NAA] and IBA in the induction of adventitious roots in sacha inchi node segments, with the aim of achieving higher survival rates during the nursery stage and field establishment.

2. Materials and Methods

The biological material consisted of botanical seeds from promising sacha inchi (*P. volubilis*) genotypes "Pinto Recodo" and "Mishquiyacu" collected in the province of Lamas, which were provided by the sacha inchi germplasm bank of the Instituto de Investigaciones de la Amazonía Peruana [IIAP], IIAP-San Martín. The *in vitro* establishment of zygotic embryos from the "Pinto Recodo" and "Mushquiyacu" sacha inchi genotypes followed the methodology described by Millones &Vásquez (2008). The germination medium was prepared using the basal salts and MS vitamins (Murashige & Skoog, 1962), supplemented with 100 mg L^{-1} of myo-inositol, 0.1 mg L^{-1} of gibberellic acid [GA_3], 0.04 mg L^{-1} of 6-furfurylaminopurine, 25 g L^{-1} of sucrose, and 1.5 g L^{-1} of phytagel, and the pH was adjusted to 5.8. The botanical seeds of both genotypes were soaked for 15 minutes in a solution of detergent and 5% commercial bleach (Clorox, 3.5 p p^{-1} sodium hypochlorite); the seeds were then brushed along the entire periphery of the seed coat and rinsed under run-

ning water. The washed seeds were hulled and disinfected in a laminar flow hood (Figure 1a). They were treated with 70% ethanol for one minute, rinsed with sterile distilled water, and then treated with a 10% commercial bleach solution for 30 minutes, followed by three rinses with sterile distilled water. Once the seeds were disinfected, the zygotic embryos were extracted using forceps and a scalpel (Figure 1b). The extracted zygotic embryos were placed in 25 x 150 mm test tubes containing the germination culture medium (Figure 1c).

The culture medium for the growth and development of sacha inchi seedlings was prepared using basal salts and MS vitamins, 100 mg L^{-1} of myo-inositol, 30 g L^{-1} of sucrose, 1.5 g L^{-1} of phytagel, and the pH was adjusted to 5.8. The seedlings derived from the zygotic embryos from both sacha inchi genotypes cultured in vitro for approximately 90 days (Figure 1d), nodal segments with 1 to 2 axillary buds were obtained for use in the rooting experiments.

Nodal segments were placed in rooting culture media with a composition similar to that of the growth medium, except that activated charcoal (3 g L^{-1}) and different concentrations of the auxins NAA and IBA were added according to the following treatments: T1: 0.5 mg L^{-1} IBA, T2: 1.0 mg L^{-1} IBA, T3: 2.0 mg L^{-1} IBA, and T4: 0.5 mg L^{-1} NAA + 1.0 mg L^{-1} IBA. Rooting percentage, number of roots, number of leaves, and root length were evaluated during the sixth week of *in vitro* culture.

The zygotic embryos and nodal segments of sacha inchi were cultured in chambers under environmental conditions of 25 ± 1 °C, 60 µmol $m^{-2}s^{-1}$ irradiance, and a 16/8-hour photoperiod (light/dark) using 36W cold-light fluorescent lamps.

The rooted sacha inchi seedlings were acclimated in rigid trays with 40 cells, and commercial Premix #3 substrate was used. The trays were placed in an environment with 90% relative humidity and a 16/8-hour light/dark photoperiod, provided by fluorescent lamps with an intensity of 75 µmol $m^{-2}s^{-1}$, and were watered with hydroponic solutions to field capacity; then, after 35 days, they were transplanted into nursery bags containing a substrate composed of soil sandy loam and earthworm humus (2:1 ratio) (Figure 4a). At 120 days, the seedlings were transplanted to their final field location at the La Unión Annex, Amazonas, Peru (coordinates 6° 16’502” S, 78° 09’57.5” W) (Figure 4b) until flowering (Figure 4c) and fruiting (Figure 4d).

Data analysis of the morphological response of the in vitro-grown seedlings employed a completely randomized design in a factorial arrangement (Factor A: two sacha inchi genotypes; Factor B: four levels of growth regulators) with three replicates, each containing three sacha inchi seedlings. Significance between means was calculated using Tukey’s test at $p \leq 0.05$. A two-factor ANOVA was performed to analyze the combined effects of the factors. Significant differences were analyzed at $p \leq 0.05$. The data on rooting percentage and root length were transformed using $(x + 0.5)^{1/2}$. Statistical analysis of the data was performed using R software version 4.3.2.

3. Results

The zygotic embryos of the sacha inchi genotypes developed adequately in the growth medium and gave rise to seedlings (Figures 1c and d), yielding seedlings 8 cm tall (Figures 1d, 2a, and b) from which nodal segments were excised (Figure 2c) to serve as nodal segment donors for the respective rooting assays.

The nodal segments induced adventitious roots between the fifth and sixth weeks of *in vitro* culture (Figure 2c and d). Root induction showed varying responses in terms of rooting percentage and root length. However, no significant differences were observed in the variables number of roots and number of leaves (data not shown). The highest rooting percentage was recorded when 1 mg L^{-1} of IBA was used, with this response being similar in both sacha inchi genotypes (Figure 3a). Meanwhile, the greatest root length was observed when IBA was applied at concentrations of 1.0 and 2.0 mg L^{-1} in the “Mishquillacu” genotype, whereas in the “Pinto” genotype, this was observed only when 1.0 mg L^{-1} of IBA was used. When IBA was used in combination with NAA, shorter root lengths were observed. The difference was statistically significant (Figure 3b).

The seedling acclimatization stage involved *ex vitro* cultivation, which lasted 4 to 5 weeks, and the nursery establishment stage, which lasted approximately 12 weeks. The commercial Premix substrate used for the *ex vitro* acclimatization and establishment of the sacha inchi seedlings was suitable for the growth and development of seedlings from both sacha inchi genotypes, resulting in average plant heights of 40 cm, deep green leaves, and good phytosanitary condition (Figure 4a)

During the field stage, the plants began the reproductive stage 4 months after being planted in the field and reached an average height of 1.3 m, producing vigorous fruits with good phytosanitary condition (Figure 4b-d).

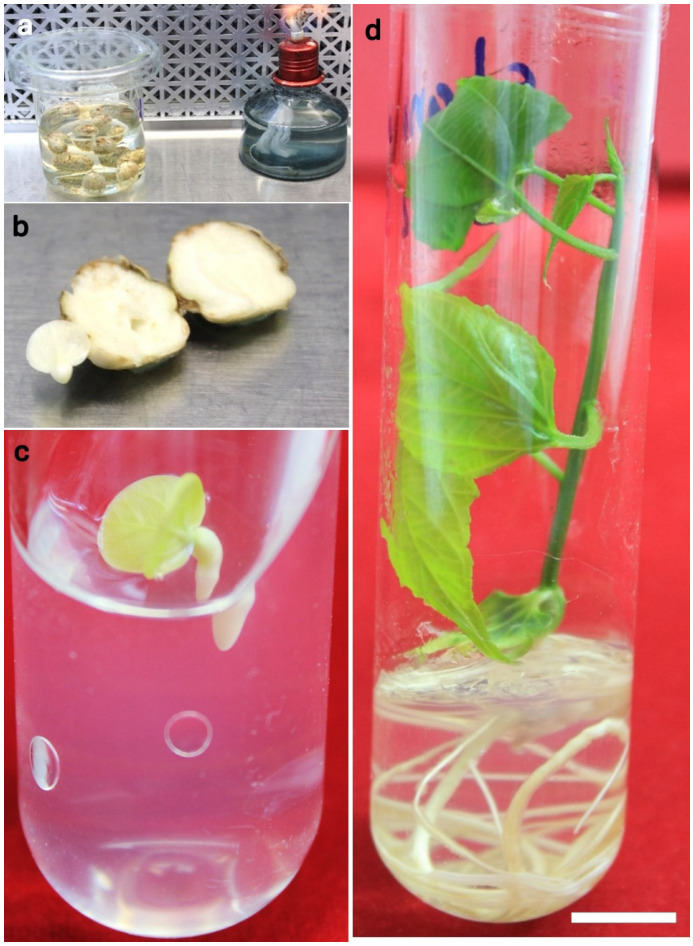

Figure 1. *In vitro* establishment of zygotic embryos from botanical seeds of sacha inchi. (a) disinfection of seeds without the episperm; (b) excision of the zygotic embryo for in vitro culture; (c) onset of zygotic embryo germination after 14 days of in vitro culture; and (d) growth and development of the sacha inchi plantlet after 90 days of *in vitro* culture. White scale bar = 1 cm.

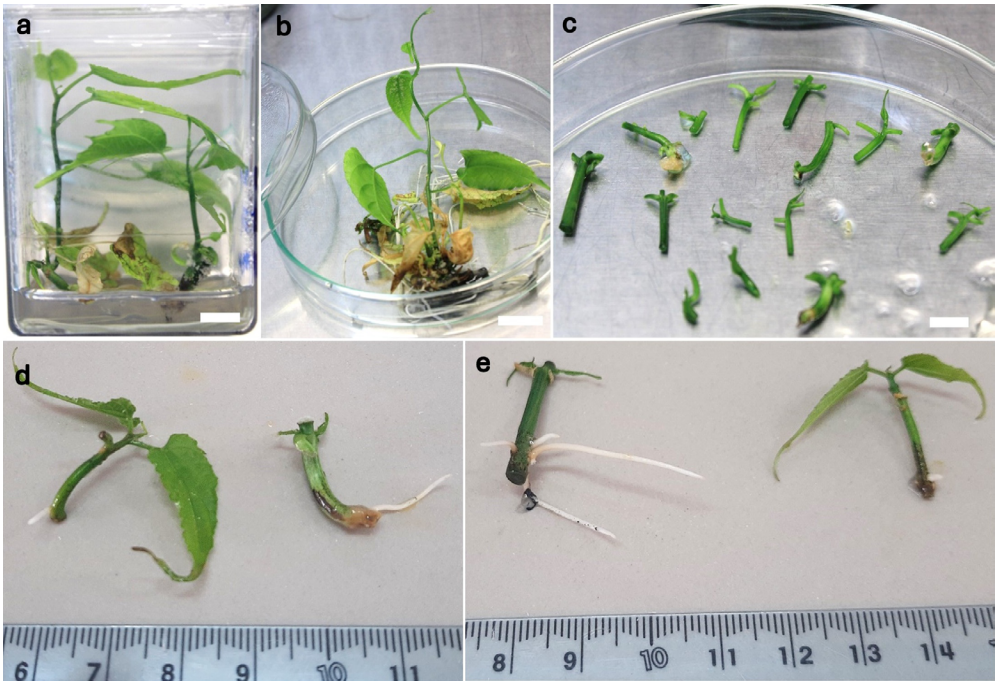

Figure 2. *In vitro* rooting of sacha inchi nodal segments after six weeks of culture. (a, b) seedlings used as donor plants for nodal segment excision; (c) preparation of nodal segments prior to transfer to rooting media; and (d, e) nodal segments showing induced adventitious roots. White scale bar = 1 cm.

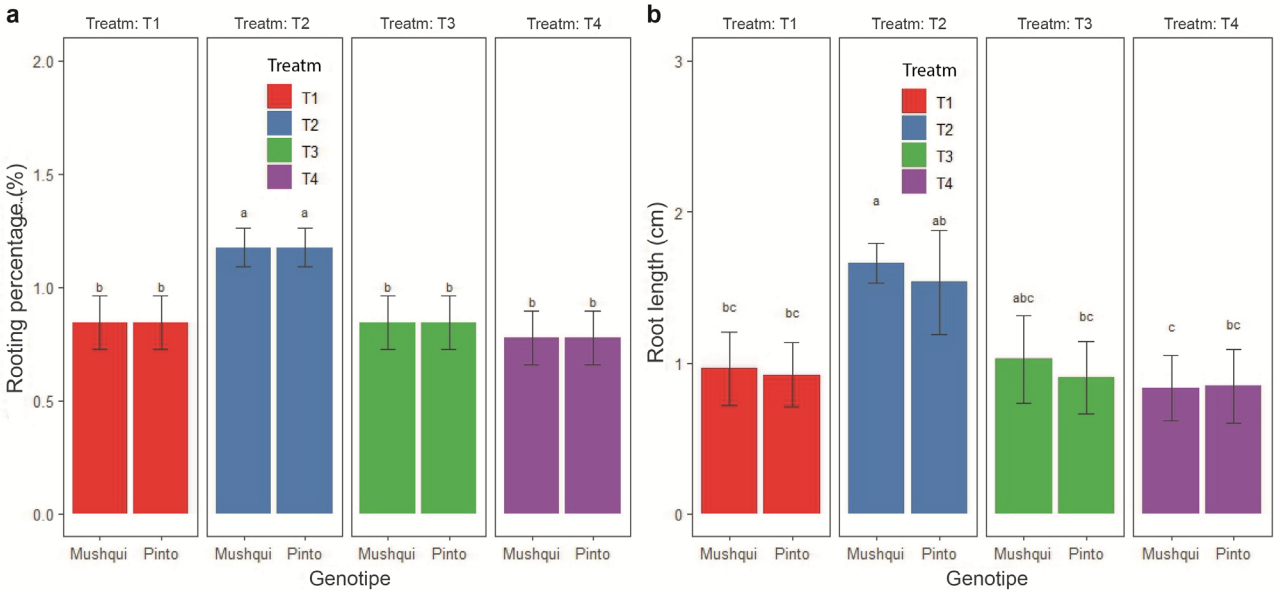

Figure 3. Morphogenic response of sacha inchi nodal segments placed in different concentrations of growth regulators. a) rooting percentage, b) adventitious root length. Data are presented as mean ± standard deviation, and different letters indicate significant differences in the parameters tested at $p \leq 0.05$ according to the Tukey test. T1: 0.5 mg L^{-1} IBA, T2: 1.0 mg L^{-1} IBA, T3: 2 mg L^{-1} IBA, T4: 0.5 mg L^{-1} NAA + 1 mg L^{-1} IBA.

Figure 4. Acclimatization and field establishment of *P. volubilis* seedlings. a) plant growth in a mesh-shade house, b) installation in an experimental plot at Anexo La Unión, Amazonas, Peru, c) seedlings at the reproductive stage, d) plants during fruit development.

4. Discussion

Cygotic embryos have been used in *in vitro* establishment because, lacking the seed coats that contain germination inhibitors, they promote uniform germination of the seedlings. The use of zygotic embryos has been reported in yellow pitahaya (Millones & Vásquez, 2010; Mállap-Detquizán et al., 2021), cultivars of *Rubus spp*. (Millones & Vásquez, 2020), *Panax ginseng* (Lee et al., 2021), and sacha inchi (Millones & Vásquez, 2008). In the present study, *in vitro* establishment was carried out by culturing endosperm-free zygotic embryos in basal medium and MS vitamins supplemented with 0.1 mg L^{-1} gibberellic acid and 0.04 mg L^{-1} 6-furfurylaminopurine, yielding up to 95% germination in the two sacha inchi genotypes; similar high germination rates were obtained by Kodahl et al. (2018) in *P. volubilis* using zygotic embryos with half the supe from the removed endosperm. This technique for culturing zygotic embryos is important in breeding programs because it allows for the complete survival of zygotic embryos for the *in vitro* regeneration of segregating populations (Niazian & Niedbala, 2020), and it also accelerates the germination process and rapid multiplication of interspecific crosses of *P. volubilis* (Kodahl et al., 2018).

The response to adventitious root induction was primarily due to growth regulators; in preliminary trials without growth regulators, the explants failed to induce adventitious roots in the genotypes used in this study (data not shown). The effect of auxins on the two sacha inchi genotypes, "Pinto Recodo" and "Mishquiyacu," showed a similar response to the growth regulators used. An adventitious root induction rate of 89.9% was obtained when 1 mg L^{-1} of IBA was used; however, when 0.5 mg L^{-1} of IB or a higher concentration (2 mg L^{-1}) was used, the induction rate decreased to 22.2%. These results are similar to those reported by Restrepo-Osorio et al. (2020), who, using a WPM basal medium and 1 mg L^{-1} of AIB, recorded 91.1% adventitious root induction. In contrast, results differing from those found in the present study were reported by Bordignon et al. (2012), who recorded up to 100% adventitious root induction when 0.5 mg L^{-1} of IBA was used.

On the other hand, the use of the combination of NAA 0.5 mg L^{-1} + IBA 1.0 mg L^{-1} reduced the percentage of adventitious root induction (11.1%) compared to when IBA was used alone. This result differs from that reported by Solis et al. (2018), who obtained a 40% rooting rate when using this combination of growth regulators. Meanwhile, *P. huayllabamba* (Bussmann et al., 2009)—a species studied by Millones and Vásquez (2008)—did not show adventitious root induction when this combination of growth regulators was used. Morphogenic responses related to root induction vary depending on the genotype of the seedlings; thus, different induction results may be obtained between the species *P. volubilis* and *P. huayllabamba*, and there may even be differences in root induction responses among genotypes of the species *P. volubilis.*

When a substrate consisting of sandy loam and worm castings (2:1 ratio) was used, the plants of both sacha inchi ecotypes achieved good growth and development, resulting in seedlings that were healthy and vigorous. In this regard, the use of sandy loam mixed with vermicompost allows for greater moisture retention and better aeration; the seedlings take advantage of these conditions to better establish their root systems, thereby facilitating proper seedling growth (Díaz et al., 2004).

For the purposes of genetic improvement and *ex situ* conservation, *in vitro*-germinated zygotic embryos can be used to preserve the maximum variability of the species; since it is an allogamous plant, a large number of parental plants are required (Valente et al., 2017). This is important because another challenge with tropical plants such as sacha inchi is that the seeds quickly lose the viability of their zygotic embryos; as a recalcitrant species, its seeds lose viability in less than a year, Amadi et al. (2018) report that *P. conophora* seeds are recalcitrant and suggest that to extend seed viability by six to seven months, they should be stored at 7 °C. Furthermore, since growth regulators were not used, the nodal segments did not form callus, which helps reduce the likelihood of inducing somaclonal variation—a factor that is important in in vitro propagation for preserving the genetic constitution of the explants.

5. Conclusions

The use of IBA alone at a concentration of 1 mg L^{-1} resulted in the highest percentage of adventitious root induction in nodal segments of sacha inchi genotypes by the sixth week of *in vitro* culture. The sacha inchi genotypes did not show significant differences in their response to adventitious root induction. The use of the commercial premix substrate in the acclimatization phase was effective in ensuring the survival of the two promising sacha inchi genotypes during the nursery and final field stages.

Acknowledgments

The authors thank the Vice-Rectorate for Research of the Universidad Nacional Toribio Rodríguez de Mendoza del Amazonas, for the support and facilities provided for the execution of this research.

Contributor roles

- Franclin Alva Zabaleta: conceptualization, methodology, validation, writing—original draft.
- Ernestina Rosario Vásquez Castro: methodology, validation, writing—original draft.
- Carlos Eduardo Millones Chanamé: methodology, supervision, formal analysis, validation, writing—review & editing.

Data Availability

Data will be available on request.

Artificial Intelligence Use Statement

The authors declare that Artificial Intelligence was not used in the preparation of this manuscript.

Ethical Implications

The authors declare that no artificial intelligence has been used in the preparation of the manuscript.

Conflict of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

Agbo, E.A., Ugese, F.U., & Baiyeri, P.K. (2015). Vegetative propagation of African walnut (*Plukenetia conophora*) using pre-treated stem cuttings of varied physiological ages. *Agro-Science*, *13*(1), 37-43.https://doi.org/10.4314/as.v13i1.6

Amadi, J.O., Appah, O.R., Ibode, T.R., & Agbonavbare, O.R. (2018). Effect of temperature and duration of storage on viability of *Plukenetia Conophora* (Walnut) mull arg seeds using tetrazolium test. *International Journal of Research Agricultural Science*, *5*(2), 104-107. https://www.ijras.org/index.php/archive?view=publication&task=show&id=296

Bordignon, S. R., Ambrosano, G. M. B., & Rodrigues, P. H. V. (2012). Propagação *in vitro* de sacha inchi. *Ciência Rural*, *42*(7), 1168–1172. https://doi.org/10.1590/S0103-84782012005000049

Bussmann, R. W., Téllez, C., & Glenn, A. (2009). *Plukenetia huayllabambana* sp. nov. (Euphorbiaceae) from the upper Amazon of Peru. *Nordic Journal of Botany*, *27*(4), 313–315. https://doi.org/10.1111/j.1756-1051.2009.00460.x

Díaz, L. P., Medina, L. F., Latife, J., Digonzelli, P. A., & Sosa, S. B. (2004). Aclimatación de plantas micropropagadas de caña de azúcar utilizando el humus de lombriz. *RIA. Revista de Investigaciones Agropecuarias*, *33*(2), 115-128. https://www.redalyc.org/articulo.oa?id=86433208

Feng, C., Zhu, Y., Su, Q., Zhou, X., Chen, W., Tao, Y.-B., Chen, M., He, H., Pan, B.-Z., Xu, Z.-F., & Fu, Q. (2025). Reproductive biology of *Plukenetia corniculata Sm*. (Euphorbiaceae), a traditional wild vegetable in Southeast Asia. *Genetic Resources and Crop Evolution*, *72*(1), 107–119. https://doi.org/10.1007/s10722-024-01967-8

Gillespie, L. J. (1993). A synopsis of neotropical *Plukenetia* (Euphorbiaceae) including two new species. *Systematic Botany, 18*(1),575–92. https://doi.org/10.2307/2419535

Henao Ramírez, A. M., Urrea Trujillo, A. I., & Atehortúa Garcés, L. (2021). *In vitro* germination and vegetative propagation through bud development of sacha inchi (*Plukenetia volubilis* L.). *Acta Biológica Colombiana*, *27*(1), 70-78. https://doi.org/10.15446/abc.v27n1.88727

Istiandari, P., & Faizal, A. (2025). Integrating *in vitro* cultivation and sustainable field practices of sacha inchi (*Plukenetia volubilis* L.) for enhanced oil yield and quality: A Review. *Horticulturae*, *11*(2), 194. https://doi.org/10.3390/horticulturae11020194

Kim, D.-S., & Joo, N. (2019). Nutritional composition of sacha inchi (*Plukenetia Volubilis* L.) as affected by different cooking methods. *International Journal of Food Properties*, *22*(1), 1235–1241. https://doi.org/10.1080/10942912.2019.1640247

Kodahl, N., García-Dávila, C. R., Cachique, D., Sørensen, M., & Lütken, H. (2018). An *in vitro* seed germination protocol for *Plukenetia volubilis* L. *Acta Horticulturae*, (1201), 549–554. https://doi.org/10.17660/ActaHortic.2018.1201.73

Lee, J.-W., Do, G.-R., Jo, I.-H., Hong, C.-E., Bang, K.-H., Kim, J.-U., & Park, Y.-D. (2021). Zygotic embryo culture is an efficient way to optimize in vitro growth in *Panax ginseng*. *Industrial Crops and Products*, *167*, 113497. https://doi.org/10.1016/j.indcrop.2021.113497

Mállap-Detquizán, G., Vilca-Valqui, N. C., Meléndez-Mori, J. B., Huaman-Huaman, E., & Oliva, M. (2021). Multiplicación *in vitro* de pitahaya amarilla (*Hylocereus megalanthus*) a partir de plántulas obtenidas *in vitro*. *Agronomía Mesoamericana*, 45472. https://doi.org/10.15517/am.v33i1.45472

Millones, C.E., & Vásquez, E. R. (2008). Micropropagación de plantas de sacha inchi (*Plukenetia volubilis* L.) provenientes de la provincia de Rodríguez de Mendoza, región Amazonas. *Investigaciones Amazonenses*, *2*(1), 7-11.

Millones, C. E., & Vásquez, E. R. (2010). Micropropagación de plantas derivadas de semillas botánicas de pitahaya amarilla (*Selenicereus megalanthus* Britton & Rose) provenientes de la provincia de Utcubamba, región Amazonas. *Investigaciones Amazonenses*, *4*(1), 34-38.

Millones, C. E. & Vásquez, E. R. (2020). Regeneración y enraizamiento de brotes adventicios etiolados de cultivares de zarzamora (*Rubus* sp.). *Revista de Investigaciones Altoandinas*, *22*(4), 330-342. https://doi.org/10.18271/ria.2020.195

Niazian, M., & Niedbała, G. (2020). Machine learning for plant breeding and Biotechnology. *Agriculture*, *10*(10), 436. https://doi.org/10.3390/agriculture10100436

Murashige, T., & Skoog, F. (1962). A revised medium for ra-

pid growth and bio assays with tobacco tissue cultures. *Physiologia Plantarum*, *15*(3), 473–497. https://doi.org/10.1111/j.1399-3054.1962.tb08052.x

Restrepo-Osorio, C., Gil-Correal, A., Chamorro-Gutiérrez, L., Ramírez-Ríos, V., Álvarez, J. C., & Villanueva-Mejía, D. (2020). Efficient direct shoot organogenesis and genetic stability in micropropagated sacha inchi (*Plukenetia volubilis* L.). *BMC Research Notes*, *13*(1), 414. https://doi.org/10.1186/s13104-020-05257-1

Ruiz-Solsol, H., & Mesén, F. (2010). Efecto del ácido indolbutírico y tipo de estaquilla en el enraizamiento de sacha inchi (*Plukenetia volubilis* L.). *Agronomía Costarricense*, *34*(2), 259-267. https://doi.org/10.15517/rac.v34i2.3636

Solis, R., Cachique, D., Guerrero-Abad, J. C., Ruiz, M. E. & Tapia, L. (2018). *In vitro* propagation of sacha inchi through organoigenesis. *Pesquisa Agropecuária Brasileira*, *53*(11), 1285-1288. https://doi.org/10.1590/s0100-204x2018001100012

Solis Leyva, R., Gonzales Chanzapa, N., Pezo Najar, J. M., Arévalo López, L. A., & Vallejos Torres, G. (2019). Rooting of sacha inchi (*Plukenetia volubilis*) juvenile cuttings in microtunnels. *Acta Agronómica*, *68*(1), 35-40. https://doi.org/10.15446/acag.v68n1.72101

Valente, M. S. F., Lopes, M. T. G., Chaves, F. C. M., Pantoja, M. C., Sousa, F. M. G., & Chagas, E. A. (2017). Molecular genetic diversity and mating system in sacha inchi progenies. *Pesquisa Agropecuária Tropical*, *47*(4), 480–487. https://doi.org/10.1590/1983-40632017v4749799

Valles, C. R. (1990). El "sacha inchi", planta nativa de importancia proteica y aceitera promisora para la selva alta. UNSM, Tarapoto. Separata.

Wang, S., Zhu, F., & Kakuda, Y. (2018). Sacha inchi (*Plukenetia volubilis* L.): Nutritional composition, biological activity, and uses. *Food Chemistry*, *265*, 316–328. https://doi.org/10.1016/j.foodchem.2018.05.055