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Rapa Nui as an untapped genetic reservoir of *Coffea arabica* in the South Pacific

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Abstract

Rapa Nui preserves an isolated lineage of *Coffea arabica var. Typica* with remarkable genetic purity, high homozygosity, and distinctive biochemical and sensory traits. Integrated genetic, sensory, and chemical analyses reveal its potential as a unique clonal reservoir with value for conservation and climate resilience. These findings highlight the island's relevance for specialty coffee, sustainable development, and diversification of global Arabica genetic resources.

Introduction

Rapa Nui (Easter Island) harbors an ancestral lineage of *Coffea arabica* var. *Typica*, preserved through centuries of geographic isolation. Genetic and chemical analyses confirm its purity, high homozygosity, and distinctive bioactive profile. Combined with unique soil and climate conditions, these findings highlight the potential of the island as a genetic reservoir. This perspective examines its relevance for specialty coffee, sustainable development, and conservation under growing climate challenges and pressures on global coffee diversity.

The outlook for the global coffee market in 2025 reveals a complex and tightly balanced scenario. World production is forecast to grow modestly, with estimates suggesting an annual increase of approximately 1.7%, reaching around 175 million 60-kg bags[1]. At the same time, global consumption is projected to reach 172.45 million bags in the 2024/2025 coffee year, reflecting sustained demand growth; historical data from 2022–2024 confirms this trend, with annual consumption consistently nearing 172 million bags[1]. This near-equilibrium between supply and demand underscores the sensitivity of the market to disruptions, whether climatic, economic, or geopolitical. Brazil remains the dominant global producer and exporter, accounting for more than half of total output, followed by Vietnam, Indonesia, and Colombia[1]. Such concentration in production among a handful of countries further underscores the importance of exploring new origins and diversifying supply chains, especially amid environmental stress and evolving consumer expectations.

Global coffee cultivation is dominated by two species: *Coffea arabica* and *Coffea canephora*, commonly referred to as *Arabica* and *Robusta,* respectively[2]. Among these, *C. arabica* is the preferred species for the specialty coffee segment, which prioritizes exceptional sensory and physical attributes in both green and roasted beans. Representing approximately 70% of global production, *Arabica* is prized for its distinctive aromatic complexity, typically described by notes of sweetness, floral undertones, and balanced acidity[2–4]. This sensory profile, combined with the species' market prestige, underpins its central role in premium coffee markets worldwide.

The term "specialty coffee" refers to a category of coffee that consistently exceeds the quality standards of conventional commercial grades, scoring over 80 points on the Specialty Coffee Association (SCA) scale. This designation is based on the presence of distinct and desirable organoleptic attributes, such as aroma, flavor, acidity, and balance, that contribute to a refined sensory experience [5]. In recent years, global production trends have shifted significantly, with a growing number of producers transitioning from commodity-grade cultivation to specialty coffee systems in response to rising market demand and price premiums[3].

The shift toward specialty coffee production is largely driven by its economic benefits. Higher quality standards allow producers to access premium markets, where differentiated coffees command significantly better prices. This creates stronger profitability incentives, particularly for smallholder farmers who adopt careful cultivation, processing, and quality assurance practices throughout the value chain. This transformation is further reinforced by evolving consumer preferences that emphasize traceability, geographic origin, post-harvest processing methods, sensory attributes, and the identity of the producers themselves[2].

Coffee is produced and exported by more than 60 tropical and subtropical countries worldwide[6]. The emergence of new producing origins plays an increasingly important role, not only in meeting global demand, but also in contributing novel sensory profiles and cultural value. These distinct characteristics often arise from unique combinations of soil and climate conditions, traditional agricultural knowledge, and locally adapted post-harvest techniques. Diversifying the geographic base of coffee production offers a pathway to strengthen the global market while promoting socio-economic development in underutilized agricultural regions. When cultivated under such unique conditions, these origins can yield coffees with exceptional qualities that enhance both market differentiation and local value generation.

The potential of Rapa Nui for the cultivation of *Arabica* coffee

Henua is a fundamental term in the Rapa Nui language, meaning "land", concepts closely tied to the cultural recognition of the Rapa Nui people. In their worldview, henua represents both the mother and the provider, an essential symbol that endures in their oral traditions[7]. These traditions preserve the memory of the various food varieties cultivated on the island, and this knowledge remains an integral part of the historical identity of the inhabitants of Rapa Nui.

Rapa Nui (Easter Island), located at 27°6′S and 109°21′W in the southeastern Pacific Ocean, is a Chilean island of volcanic origin with a total area of 163.6 km² (Fig. 1). Approximately 19% of this land, roughly 3,134 hectares, is allocated to agricultural use, supporting the cultivation of crops such as sweet potato, taro, yam, banana, maika, pumpkin, and sugar cane among others[8].

With a population of approximately 7,750 inhabitants, Rapa Nui is part of a Polynesian cultural and ecological zone, yet it possesses distinctive edaphoclimatic features due to its geographic location south of the Tropic of Capricorn[8]. Unlike many other Pacific islands, Rapa Nui has specific climatic conditions, lower solar radiation, and cooler average temperatures, ranging from 16°C to 28°C, evidencing three seasonal groups: dry seasons (October to February), transitional seasons (March, August, September), and wet seasons (April to July)[9]. Annual precipitation varies from year to year. Currently, a total of 1,130 mm is recorded. In 2013 and 2024, accumulations were relatively close to normal, with 1,109 mm and 1,090 mm, respectively. However, the trend indicates that precipitation is becoming increasingly scarce. In fact, 2022 was the driest year on record, with only 597 mm, about half the normal amount; 1954 also had only a few months of precipitation. This is combined with moderate temperature variation and persistent trade winds[8,9] . These unique environmental conditions have proven favorable for the cultivation of *C. arabica,* offering a rare microclimate that supports growth outside the conventional tropical coffee belt.

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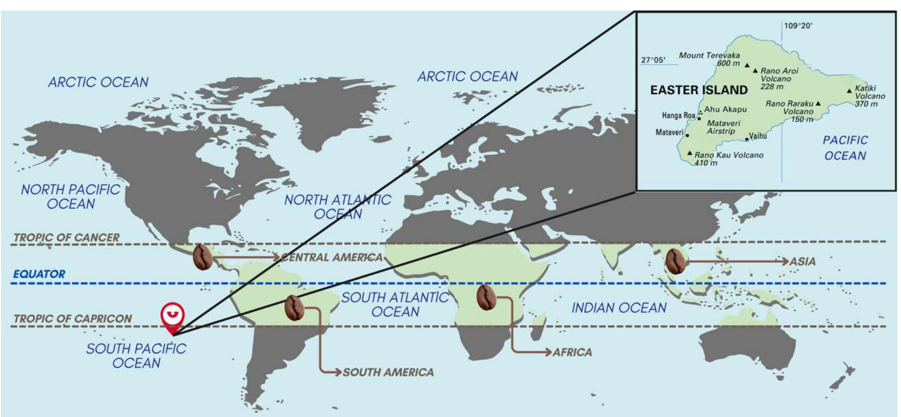

Fig 1. Location of the island of Rapa Nui (Easter Island). The island is located near the "coffee belt" located between 25°N and 30°S. The Coffee Belt surrounds the Equator, passing through Central and South America, Asia, and Africa.

Historical and genetic analyses trace the origins of *C. arabica* to the highlands of Ethiopia, from where it was introduced to the Arabian Peninsula (present-day Yemen) during the 14^{th} century[10]. This early domestication established a lineage that has been continuously cultivated for over five centuries. The species began its global dispersion in the early 18^{th} century through two primary genetic branches: *Typica* and *Bourbon*, which now underpin the majority of commercial *C. arabica* cultivars worldwide[11].

On Rapa Nui, coffee, locally known as Kape, is believed to have arrived in the 19^{th} century, likely introduced by the Sheep Exploitation Company and missionaries from Mangareva and Tahiti[12]. Remarkably, these plants adapted to the wild conditions of the island with minimal human intervention, leading to the preservation of a relatively undisturbed gene pool over more than a century. This prolonged isolation has protected the genetic integrity of the population, which continues to thrive spontaneously in household gardens and across diverse microhabitats throughout the island[12]. Recognizing the conservation value of this lineage, the Ma'u Henua Indigenous Community launched a formal initiative in 2018, establishing a planting of 400 *Typica* trees (Fig. 2). These efforts mark an important step toward safeguarding and revitalizing a unique, insular expression of *C. arabica.*

Fig 2. Flowering of *Coffea arabica* var. *Typica* of Rapa Nui, exhibiting its characteristic axillary inflorescence with white flowers and elliptical leaves. Photos provided by Ka Tonga Te Mana'u from the Ma'u Henua Indigenous Community.

Deciphering the sensory imprint of Rapa Nui coffee.

A sensory evaluation of seven coffee samples from Rapa Nui was conducted following the SCA standardized protocol, which focuses on the assessment of inherent organoleptic qualities of green and roasted coffee[5]. Samples labeled RNF01 (Tahai) and RNL02 (Kainga), processed using the washed method, are the focus of the present investigation. Five additional samples, RN201, RN202, RN101, RN203, and RN204, were processed using the honey method and previously evaluated in 2023 by Q Arabica Grader Juan Sebastián Gómez Ocampo. All data was provided by the coffee producer consulting firm Ka Tonga Te Mana'u from Rapa Nui.

The sensory analysis revealed a consistent presence of positive descriptors across all samples. Notes of honey, panela, vegetal tones, sugarcane, tobacco, and woody elements were recurrent. Evaluators also detected medium-intensity citric acidity, a light body, and lingering nutty nuances, suggesting a delicate and distinctive profile. The washed samples (RNF01 and RNL02) shared several attributes with the earlier honey-processed samples, including caramel, raisin, hazelnut, almond, vanilla, and floral hints such as chamomile. The consistency in sweetness and aromatic complexity across processing methods reflects a strong intrinsic sensory signature linked to the island's terroir.

Attributes such as fragrance/aroma, flavor, residual flavor, acidity, body, uniformity, sweetness, clean cup, balance, and final score were evaluated (Fig. 3). While washed samples (green and cyan lines) exhibited slightly lower final scores, they maintained comparable profiles across most parameters—underscoring the genetic and environmental stability of the Rapa Nui coffee phenotype.

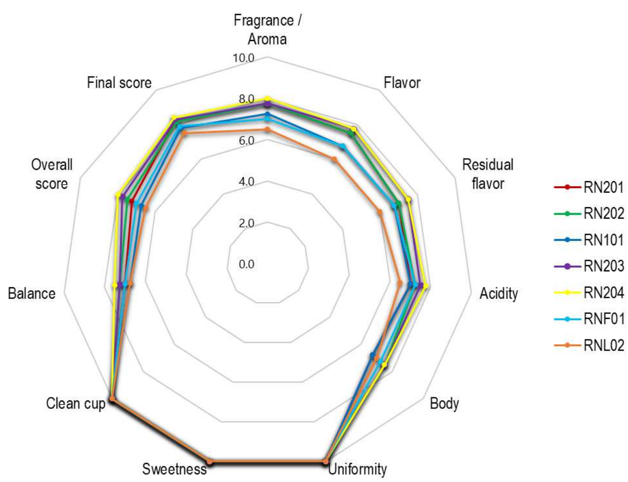

Figure 3. Comparative spider plot showing the sensory attributes of seven coffee samples from Rapa Nui Island, assessed using the Specialty Coffee Association (SCA) protocol. Evaluated attributes include fragrance/aroma, flavor, residual flavor, acidity, body, uniformity, sweetness, clean cup, balance, overall score, and final score. Samples RNF01 and RNL02 (washed process) are included in the current study, while samples 201, 202, 101, 203, and 204 (honey process) were previously evaluated in 2023 by Q Arabica Grader Juan

Sebastián Gómez Ocampo. Each sample is represented by a distinct color. The plot highlights consistent sensory performance across samples and processes, with notable similarities in sweetness, cleanliness, and balance. The data was provided by the consulting firm Ka Tonga Te Mana'u from Rapa Nui.

These preliminary findings suggest that Rapa Nui coffee is not only agronomically viable but also sensorially distinct, with the potential to establish itself as a differentiated origin in the specialty coffee market. Similar to other island coffees, such as Jamaica's Blue Mountain with its smooth body and floral cocoa notes; Hawaii's Kona with bright acidity and fruity complexity; and Sumatra's earthy, full-bodied Giling Basah style[13–15]. Rapa Nui's edaphoclimatic conditions support the development of an exotic flavor profile shaped by localized post-harvest practices. Through careful processing adapted to its unique soil and climate, Rapa Nui coffee can express a high-value organoleptic identity. This potential, combined with cultural heritage and ecological sustainability, positions the island as a candidate for recognition within the global landscape of specialty coffee origins.

Chemical Composition and Its Relationship with Sensory Potential

To complement the sensory evaluation, a chemical analysis of bioactive compounds was conducted using high-performance liquid chromatography (HPLC)[16]. The objective was to quantify key compounds in green coffee beans cultivated on Rapa Nui, specifically caffeine, trigonelline, and chlorogenic acids (CGA), which are closely linked to both the sensory quality and functional potential of coffee[17].

Caffeine ($C_8H_{10}N_4O_2$), a primary alkaloid in coffee, is recognized for contributing to bitterness and providing stimulant effects through its action on the central nervous system[18–

[20]. Trigonelline ($C_7H_7NO_2$), formed by the methylation of nicotinic acid, plays a dual role: it enhances aroma during roasting and is associated with bioactive properties such as neuroprotection and antimicrobial activity[19,20]. Chlorogenic acids, the primary class of phenolic compounds in green coffee, comprise hydroxycinnamic acid derivatives, including caffeic, ferulic, p-coumaric, and sinapic acids, which affect both health-promoting antioxidant capacity and sensory traits, particularly acidity and astringency[19,21,22].

The chemical analysis of Rapa Nui samples revealed caffeine concentrations of 0.89% and 1.00% (w/w, dry mass) for RNF01 and RNL02, respectively. Trigonelline content was measured at 1.33% in RNF01 and 1.28% in RNL02, while chlorogenic acid concentrations were 1.75% and 2.04%, respectively. These values place Rapa Nui coffee within the lower to moderate range of global variation, particularly in relation to data from other *C. arabica* cultivars. For example, studies by Gichimu[19] report CGA concentrations between 5.37% and 7.95%, caffeine levels ranging from 1.01% to 1.54%, and trigonelline between 0.95% and 1.00% in *C. arabica* variety Ruiru 11 and pure, non-introgressed Arabica SL-28 cultivars. Similarly, Wale[20] observed CGA values of 3.29% to 7.73%, caffeine between 0.78% and 1.55%, and trigonelline ranging from 0.53% to 1.27% in coffee samples from Ethiopia's East Gojjam zone.

Despite the lower CGA content in the Rapa Nui samples relative to these African cultivars, the trigonelline values are notably elevated and consistent, suggesting a biochemical profile that may favor sweetness, aromatic complexity, and overall cup smoothness[23]. These findings correlate with the sensory attributes described previously, particularly the medium citric acidity, light body, and recurring notes of honey, panela, sugarcane, and nutty tones. The moderate caffeine and CGA levels likely temper bitterness and astringency, while the higher trigonelline concentrations enhance the perception of sweetness and floral or caramel-like aromas following roasting.

Taken together, the chemical and sensory analyses point to a distinctive biochemical fingerprint for Rapa Nui coffee. This profile supports its emerging identity as a differentiated origin, capable of producing unique flavor experiences under properly tailored processing methods. In addition to its potential agronomic and genetic value, the compositional profile strengthens the case for Rapa Nui coffee as a high-quality, origin-specific product in the specialty market.

Rapa Nui as a Genetic Reservoir: Insights from DNA Fingerprinting

The distinctive chemical and sensory profiles observed in Rapa Nui coffees, characterized by elevated trigonelline content, moderate levels of chlorogenic acids, and recurring notes of honey, panela, and nutty undertones, raise an important question: could these traits be linked to a unique genetic background? To explore this, molecular analyses were conducted to determine the lineage and diversity of the *C. arabica* populations on the island (Fig. 4). Establishing a genetic basis is essential for understanding the origin of these compositional and sensory features and for assessing their potential for conservation and breeding.

Fig 4. Drupes of *Coffea arabica* var. *Typica*, in the wild, found on Rapa Nui, shows its adaptation to the subtropical island climate. The photographs were provided by the consulting firm Ka Tonga Te Mana'u of Rapa Nui.

Recent investigations have confirmed the presence of long-established populations of *C. arabica* on Rapa Nui, prompting molecular analysis to determine their taxonomic and genetic identity. Using DNA fingerprinting techniques based on simple sequence repeat (SSR) markers, researchers identified these plants as belonging to the *Typica* lineage of *C. arabica* L., one of the two primary ancestral lineages derived from the original dissemination of coffee from Yemen during the early 18th century[11,24,25]. This classification places the Rapa Nui specimens as direct descendants of *Typica*, as illustrated in the evolutionary lineage of *C. arabica* (Fig. 5), and reinforces the island's potential as a reservoir of early, genetically pure Arabica germplasm.

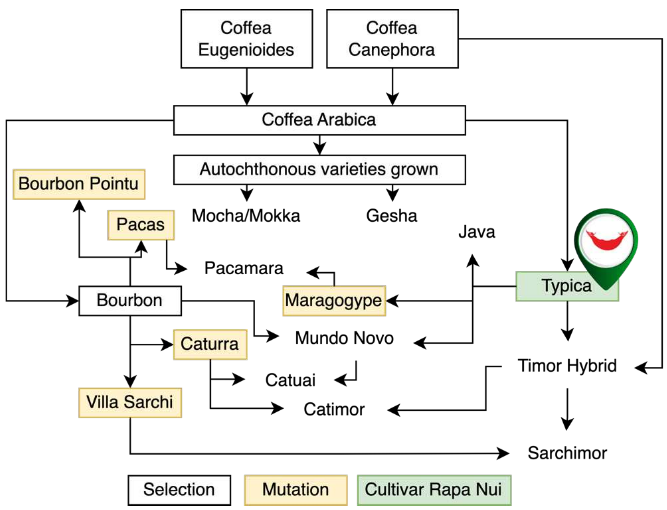

Fig 5. Classification and nomenclature of the species, subspecies and varieties of the coffee plant (Hernando, 2023)**.**

To support this classification, a systematic random sampling was conducted across two archaeological zones on the island: Tahai (27°08'24.0"S, 109°25'25.6"W) and Kainga (27°14'03.64"S, 109°42'29.94"W). In each site, 50 m² plots were delimited, and fruits were collected from approximately 15 individual plants. Samples were labeled as RNF01 (Tahai) and RNL02 (Kainga) to ensure traceability. These samples were subjected to molecular analysis to determine their genetic profile.

The DNA fingerprinting process involved DNA extraction from three randomly selected grains per sample, followed by fragmentation using restriction enzymes, separation via gel electrophoresis, and hybridization through Southern blotting[27]. The PCR and STR analyses were applied to amplify and detect short, highly variable DNA sequences, producing a banding pattern that functions as a genetic barcode.

The SSR profiles for RNF01 and RNL02 were identical across all 11 loci analyzed (Table 1), with both alleles showing the same fragment lengths at each marker. This result suggests a high level of homozygosity, which may reflect long-term vegetative propagation, a narrow founder effect, or genetic drift due to the island's geographic isolation[28]. The uniformity in allele patterns indicates that these populations likely derive from a single genotype or a genetically homogeneous group, preserved over generations without external genetic input[29].

Table 1. Results obtained from DNA Fingerprinting analysis*.

SSRs	**Allele**	**Code ADN**	
		RNF01	**RNL02**
1-Sat11	1	145	145
	2	145	145
2-CBD-Sat207	1	83	83
	2	93	93
3-Sat225	1	265	265
	2	298	298
4-Sat235	1	257	257
	2	257	257
5-Sat24	1	161	161
	2	161	161
6-Sat244	1	278	278
	2	306	306
7-Sat254	1	202	202
	2	202	202
8-Sat29	1	119	119
	2	133	133
9-Sat32	1	105	105
	2	129	129
10-Sat41	1	148	148
	2	148	148
11-Sat47	1	117	117
	2	150	150

*Developed by the company RD2 Vision. Alleles, coded as a number of 11 markers, are observed in each sample.

This genetic stability is further supported by the evolutionary placement of the Rapa Nui samples within the *Typica* group (Fig. 5). The diagram highlights Typica's divergence from other *C. arabica* cultivars and its foundational role in the development of modern coffee varieties. The identification of a non-introgressed *Typica* lineage on Rapa Nui provides compelling evidence that the island may function as a living clonal garden, one that has maintained genetic traits lost or diluted in other regions due to hybridization and modern breeding efforts[24,25].

These findings represent the first molecular characterization of *C. arabica* in Rapa Nui and mark an important step toward understanding the island's unique genetic resource. Given the global challenges facing Arabica cultivation, including disease susceptibility, climate sensitivity, and declining genetic diversity, the preservation and further study of this isolated *Typica* lineage could contribute to future breeding programs and strategies to enhance resilience and sustainability in coffee agriculture.

Rapa Nui's potential as an unexplored clonal garden

The island ecosystem of Rapa Nui, located in the southeastern Pacific Ocean, represents a rare biogeographic enclave that has enabled the long-term preservation of a genetically distinct lineage of *C. arabica* var. *Typica* (Fig. 6). Isolated from global coffee production networks for over a century, Rapa Nui has maintained a germplasm that exhibits both genotypic purity and phenotypic integrity[8]. This lineage, confirmed through DNA fingerprinting, has remained largely untouched by hybridization or breeding interventions, positioning the island as a natural repository of early *C. arabica* genetic material.

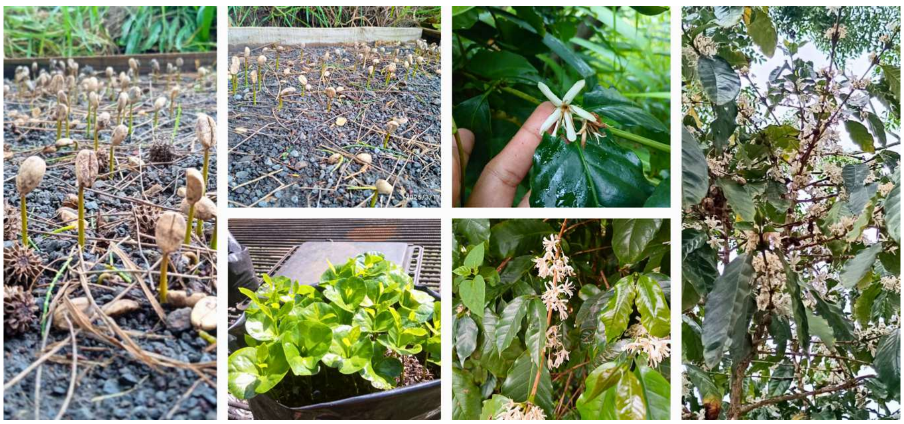

Fig 6. Flowering, germination, and vegetative growth of *Coffea arabica* var. *Typica*, eedlings in the wild. The photographs were provided by the consulting firm Ka Tonga Te Mana'u of Rapa Nui.

One of the biological mechanisms facilitating this stability is the species' intrinsic capacity for self-pollination, which enables fertilization in the absence of biotic vectors[24,30]. Although *C. arabica* is capable of cross-pollination via wind (anemophily) or animal activity (zoophily), such events remain rare in isolated systems like Rapa Nui[31]. This limited gene flow has reduced the likelihood of introgression from external genetic sources, thereby preserving the original *Typica* genotype. The geographic isolation of the island has therefore acted as an unintentional, yet highly effective, mechanism for in situ genetic conservation.

This unspoiled lineage holds considerable value as a biotechnological resource. The preservation of unique allelic combinations and phenotypic traits not only contributes to biodiversity but also offers strategic advantages for breeding and resilience research[29]. As shown in Fig. 6, the existence of wild or unmanaged plants across microhabitats suggests a system of passive clonal propagation that could be leveraged for cultivar stabilization and propagation[29].

Interestingly, while *C. arabica* is typically associated with high-altitude agroecosystems above 1,400 meters, specimens from Rapa Nui have adapted to lower altitudes, higher temperatures, and distinct edaphoclimatic conditions[32]. This unexpected adaptability signals the presence of genotypes with enhanced plasticity, traits that are increasingly critical as climate change reshapes the environmental limits of coffee production[33]. Rapa Nui thus represents not only a conservation stronghold, but also a living laboratory for examining Arabica performance under non-traditional conditions.

The implications of these findings are twofold. First, they underscore the importance of preserving this isolated *Typica* lineage as part of global efforts to broaden the genetic base of *C. arabica*, which remains narrow and vulnerable to climatic and pathogenic threats. Second, they open new avenues for research into adaptation mechanisms and genotype-environment interactions in marginal coffee-growing zones. In this sense, Rapa Nui can be viewed as a "clonal garden" of global significance, an overlooked yet potent contributor to the genetic resilience and sensory diversity of future coffee landscapes.

Future Scenarios for Coffee Development in Rapa Nui

The development of coffee production in Rapa Nui stands at a critical inflection point. Despite the historical introduction of coffee in the 19th century, likely through the Easter Island Exploitation Company, the island's cultivation efforts remained largely informal until recently. It was not until 2018 that a coordinated reactivation took place, led by the Ma'u Henua Indigenous Community. This initiative emphasized community engagement, particularly involving children in participatory planting efforts, and marked the beginning of a structured approach to establishing coffee as part of the island's agricultural identity[34].

Currently, approximately 400 coffee plants, most reaching 1.20 meters in height, are entering their productive phase with estimated yields of one kilogram of green coffee per plant. However, one of the primary constraints limiting the expansion and sustainability of coffee cultivation is water availability. While *C. arabica* can be cultivated under rainfed conditions, its productivity and long-term viability are strongly dependent on reliable precipitation, which is increasingly unpredictable in island ecosystems. In response, local initiatives have begun exploring innovative solutions such as atmospheric water harvesting technologies capable of capturing up to 5,000 liters per day, alongside other adaptive strategies[32].

A distinguishing feature of Rapa Nui is the integration of traditional ecological knowledge with sustainable practices. The conservation initiative "Conservación de la flora nativa de Rapa Nui, Isla de Pascua" is revitalizing the ancestral manavai circular stone gardens, which retain moisture and shield plants from wind, as low-cost, low-maintenance structures that protect native flora and serve as living demonstrations of climate change adaptation (Fig. 7). The island's agricultural practices, historically complemented by "stone gardens" and "pu oka" pits, have resulted in a resilient, diversified agricultural matrix that has enabled the island's society to withstand drought and temperature fluctuations. This synthesis of tradition and innovation presents a promising model of low-impact agriculture, which is uniquely suited to the environmental constraints experienced on Rapa Nui[35].

Fig 7. Coffee plant production using ancestral gardens known as "manavai circulares de piedra" (circular stone gardens), Rapa Nui. Photos taken from the Manavai conservation project[36].

In envisioning a path forward, Rapa Nui can draw strategic inspiration from other island-based specialty coffee origins. In Ka'ū, Hawaii, coffee cultivation only began two decades ago, yet the region has rapidly gained international prestige. This success has been underpinned by favorable volcanic soils, consistent rainfall, altitudes between 457 and 640 meters, and a deliberate embrace of sustainable practices such as permaculture and experimental processing techniques[37]. Similarly, Jamaica's Blue Mountain region has built a globally recognized brand by combining rigorous quality standards, ideal agroecological conditions (610–1,370 masl, high humidity, fertile soils), and integration with cultural and experiential tourism[38]. These examples demonstrate that even small islands, with limited land area, can achieve international recognition and economic value through differentiation, quality control, and territorial branding.

Rapa Nui is well-positioned to follow a similar trajectory. The presence of a local consumption infrastructure, evidenced by numerous active coffee shops, provides a foundation for internal market development[39]. Moreover, coffee cultivation could be integrated into the island's broader cultural and tourism sectors through guided tours, cupping workshops, and agro-educational experiences. This would diversify the island's current tourism offerings, which are primarily archaeological, and provide new opportunities for value creation rooted in agriculture and heritage.

Nevertheless, achieving this vision will require addressing persistent challenges. Chief among them is the need for water management systems tailored to the island's conditions, including atmospheric humidity collectors, rainwater harvesting, and drip irrigation. Additionally, recovering ancestral moisture retention techniques and soil practices will be essential to maintaining ecological balance. Establishing a clonal garden with varieties selected for climate resilience could further strengthen long-term viability, while investment in local capacity-building in agronomy, post-harvest processing, and sensory evaluation will be necessary to ensure community ownership and sustained quality.

If developed holistically, Rapa Nui's coffee sector could evolve into a strategic pillar for economic diversification, food sovereignty, and cultural revitalization. The island has the opportunity not only to produce exceptional coffee but also to model how small, isolated communities can build agroecological value chains that are rooted in local identity, environmentally adaptive, and globally competitive.

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Author contributions

Conceptualization and project administration, N.G.G., N.T.J., and A.B.M.; Data collection, N.T.J., A.B.M.; Methodology, N.T.J., A.B.M., M.S.R., F.S., C.M., and N.G.G.; Supervision, N.G.G., and A.B.M.; Writing original draft, N.T.J., A.B.M., and M.S.R.; Writing-review & editing, N.T.J., A.B.M., M.S.R., F.S., C.M., and N.G.G.; All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare that they have no competing interests as defined by Nature Portfolio or other interests that might be perceived as influencing the results and/or discussion reported in this article.

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