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Research article

Social-ecological resilience: Knowledge of agrobiodiversity by campesinos and migrants in the face of global changes

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ABSTRACT

There is concern that agrobiodiversity is being irreversibly eroded in the face of agricultural industrialization. While academic and policy debates stress loss of landraces, little attention has been paid to evaluating how agricultural knowledge systems endure in response to broader social-ecological changes (i.e., "system's resilience"). For being resilient, agricultural knowledge systems should incorporate new information (modern seed varieties) whilst maintaining its traditional components (landraces) and functions. However, the loss or continuing utilization of landraces may be influenced by several social-ecological filters, which are processes that selectively remove varieties according to their phenotype, local uses, or value. We examined the resilience of agricultural knowledge systems in the southern Andes. These systems include the knowledge of landraces and modern varieties by campesinos and lifestyle migrants. We further assessed the association of social-ecological filters with the knowledge of agrobiodiversity. Over four years (2018–2022), we used mixed-methods including semi-structured interviews with gardener experts and conducted knowledge exercises of seed varieties and surveys of gardeners (n = 132). We assessed the association of 'knowledge score on varieties' (general, landraces, and modern) with *a priori*-defined social-ecological filters. Gardeners with more proficient knowledge of landraces were more knowledgeable of modern varieties too. The general knowledge of agrobiodiversity and the knowledge of landraces, but not of modern varieties, was higher for campesinos than migrants. The main seed source of gardeners, the participation in seed exchanges, gardeners' origin, and gardeners' age were the social-ecological filters that influenced gardeners′ knowledge of agrobiodiversity. We highlight that social-ecological, small-scale farming systems, are being resilient when they have the capacity of incorporating new information (knowledge of modern varieties) whilst maintaining their identity (knowledge of landraces) without undergoing a major shift in their basic structures and functions in this Important Agricultural Heritage Site and Global Biodiversity Hotspot, and beyond.

1. Introduction

There is growing concern among researchers, farmers, activists, and politicians that, as in the case of wild biodiversity, agrobiodiversity is being eroded in the face of unprecedented global changes (IPCC, 2022). Proposed factors in the erosion of agrobiodiversity include human population pressure, rural-urban exodus, environmental degradation, climate change, the industrialization of agricultural systems, and its replacement by modern germplasm (Barthel et al., 2013; Castañeda-Navarrete, 2023). Agrobiodiversity can be quantified in terms of landraces, which are those locally adapted crop varieties that farmers have generated in a specific social-ecological context for generations, through trait selection and domestication. Landraces represent a unique source of genetic diversity (e.g. different varieties of crops may have

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varying tolerance to drought, pests, or diseases) that is crucial for future global needs, such as feeding a rising global population (Pörtner et al., 2021).

While academic and policy debates stress loss and erosion associated with agricultural industrialization, little attention has been paid to evaluating how small-scale farming systems learn and endure by incorporating new information in response to broader changes (i.e., the "social-ecological resilience") (Barthel et al., 2010; Reyes-García et al., 2014). Resilience is the system's capacity to absorb changes whilst maintaining its essential components and functions (Biggs et al., 2016). The importance of studying this concept in agriculture, is that more resilient agroecosystems are likely best prepared to cope with global changes (Altieri et al., 2015; Altieri and Nicholls, 2017). Agrobiodiversity may play a crucial role in enhancing social-ecological resilience in at least three domains. First, agrobiodiversity encompasses the genetic variation within and between crop species that provides resilience, because having a diverse genetic pool ensures that some crops will likely survive against pests, diseases, and changing environmental conditions (Bellon et al., 2011; Mercer and Perales, 2010; Ratnadass et al., 2012). Second, agrobiodiversity provides opportunities for diversified livelihoods because the cultivation of a variety of crops can help farmers spreading their risks and adapt to market fluctuations, climate variability, emerging diseases, and other stressors (Caviedes et al., 2024; Duguma et al., 2021). Third, agrobiodiversity contributes to biocultural diversity and social cohesion by fostering connections between farmers, which are essential for collective responses to environmental challenges and crises (Ibarra et al., 2024; Porcuna-Ferrer et al., 2023). Strengthening of social-ecological resilience will ultimately contribute to food security and sovereignty, human wellbeing, and sustainability (Frison et al., 2011; Ibarra et al., 2011).

Many landraces have disappeared from cultivation and, although some are preserved in national and international gene banks, researchers, farmers, and activists have emphasized that these important initiatives are not enough: it is imperative to conserve landraces *in vivo*, along with the knowledge associated with their management (Nazarea, 2005). Local agricultural knowledge is understood as a complex body of knowledge and management practices associated with small-scale farming (e.g., homegardening), including processes of crop domestication and diversification, which are characterized by continuity and intergenerationality (Galluzzi et al., 2010; Ingram, 2011).

Homegardens play a critical role for both *in vivo* conservation of agrobiodiversity (Coomes et al., 2015; Galluzzi et al., 2010) and food sovereignty in rural areas (Graeub et al., 2016; Ibarra et al., 2019b). Management of homegardens and their agrobiodiversity is highly dependent on local agricultural knowledge (Nazarea, 2006). The agrobiodiversity and associated knowledge present in homegardens depend on various non-random processes, such as social-ecological filtering, that create distinct community patterns different from that expected under random assembly (Ibarra et al., 2021b). Social-ecological filters are the coupled human-nature processes that selectively remove species or landraces, and associated knowledge, according to crop phenotype, local uses, or value (e.g., monetary; (Naeem and Wright, 2003; Wood et al., 2015). For example, ethnicity ("cultural origin") is one of the first filters of landraces and their associated knowledge in Vietnamese homegardens (Trinh et al., 2003). The age of farmers and the number of years they have managed a homegarden can also influence both, the diversity and knowledge of landraces in homegardens, as reported for Benin in Africa (Idohou et al., 2014) and in Central Italy (Negri, 2002). In Nepal and Argentine Patagonia, modern seeds provided by agricultural extension agents from the government may be producing an increasing homogeneity and filtering of local landraces in smallholding farms (Eyssartier et al., 2011; Upreti and Upreti, 2002). Despite all these associations, the potential influence of social-ecological filters on the resilience of small-scale farming systems has received little attention globally. For being resilient, a small-scale farming system should be capable of integrating modern varieties while maintaining its traditional components and functions, such as landraces. This entails the coexistence of both types of crops within homegardens.

The United Nations Food and Agriculture Organization (FAO) and individual States have identified both Globally Important Agricultural Heritage Sites (GIAHS) and Nationally Important Agricultural Heritage Sites (NIAHS). In the Andes mountains of southern Chile, the "Cordillera Pehuenche" and its surroundings have recently been recognized as a NIAHS by the Chilean State (Kaulen-Luks et al., 2022). This reflects the site's importance for the contribution to food sovereignty, high levels of agrobiodiversity, and associated knowledge (Barrena et al., 2014; Ibarra et al., 2019a; Marchant et al., 2020). This site is also located within Chile's "Valdivian Temperate Rainforest", a global biodiversity hotspot (Myers et al., 2000). The recognition as NIAHS, however, does not guarantee the resilience of agricultural systems. NIAHS are known to be threatened by multiple factors including, for example, farmers' migration due to low economic viability, which has resulted in traditional farming practices being abandoned and landraces being lost (FAO, 2018; Zhang et al., 2017). In the southern Andes, Mapuche-Pehuenche Indigenous and non-Indigenous campesinos co-inhabit with recently arrived migrants. Lifestyle migrants are urban people who voluntarily relocate to rural areas pursuing a greater connection with nature and are rapidly settling in different locations worldwide (Benson and O'Reilly, 2009). In the "Cordillera Pehuenche" NIAHS, many lifestyle migrants have incorporated homegardens into their livelihoods. However, their socio-demographic profiles and management practices may influence contrasting patterns of agrobiodiversity knowledge, in comparison to campesinos (Indigenous and non-Indigenous) who have inhabited the area for generations (Ibarra et al., 2019a; Marchant, 2017). It may be expected that the knowledge of landraces by campesinos may be considerable higher given their long history in the area, yet many lifestyle migrants have shown high levels of crop diversity in their homegardens, despite shorter historical presence in the area (Ibarra et al., 2019a). It is, therefore, imperative to better understand the resilience of local agricultural systems and the role of social-ecological filters in this changing NIAHS.

In this paper, we examined the resilience of agricultural knowledge systems. In the southern Andes, we assessed small-scale farming systems that include the knowledge of landraces and of modern varieties by campesinos and lifestyle migrants. We further assessed the influence of social-ecological filters on the knowledge of agrobiodiversity by these two types of farmers. We tested the following hypotheses: (1) In small-scale farming systems that are not being resilient, the knowledge of landraces may be replaced by that of modern varieties. Conversely, in systems being resilient, knowledge of landraces and modern varieties are likely to be complementary rather than mutually exclusive; (2) Because campesinos have a longer intergenerational connection to the area compared to lifestyle migrants, they are likely to possess more extensive knowledge of the landraces grown in their homegardens; and (3) Social-ecological filters are predicted to selectively remove knowledge pertaining to agrobiodiversity, with initial losses observed in the knowledge associated with landraces. For this examination, we conducted empirical research with global implications in an Important Agricultural Heritage System (IAHS), and its surroundings, and Global Biodiversity Hotspot of southern South America.

2. Methods

2.1. Study area

Between 2018 and 2022, we conducted this study in 30 different human settlements (localities) within the "Cordillera Pehuenche" Nationally Important Agricultural Heritage Site (NIAHS) and its surroundings, which are in the La Araucanía Region (38–39° S), southern Andes of Chile. The area has a mountainous topography in which agricultural land, vast zones of native forest, non-native tree monocultures, lakes, and rivers constitute a heterogeneous mosaic. Most of the rural population lives on farms smaller than 5 ha and Mapuche families live in close association with non-Indigenous rural families (descendants of migrants who arrived in the early twentieth century (Barreau et al., 2019);). The agricultural system of local families (i.e., campesinos) generally includes households with an associated homegarden, *chacras* (fields planted with potato, maize, or fava beans), a *quinta* (fruit orchard), and small pastures for livestock (Barreau et al., 2016). Pre-Hispanic crops are still grown in the area, such as more than 50 landraces of beans (*Phaseolus vulgaris, Phaseolus coccineus, Vicia faba*), peas (*Pisum sativum, Lathyrus sativus*), and quinoa (*Chenopodium quinoa*; (Ibarra et al., 2019a; Urra and Ibarra, 2018).

2.2. Field methods

Fieldwork was conducted in four seasons (2018–2022) between October and March, which are the months with the most number and intensity of gardening activities in the area. Educated free prior informed consent was obtained beforehand conducting the research. This study was approved by the Ethics Committee of the Pontificia Universidad Católica de Chile (protocol codes 170714019–27 April 2018 and 190,603,004–24 April 2020).

2.2.1. Semi-structured interviews

We conducted semi-structured interviews with 10 expert gardeners (elder women seedkeepers with numerous family generations living and cultivating a homegarden in the study area). The interview included questions regarding changes on agrobiodiversity over the last decades to determine one very well-known, one moderately known, and one little-known landrace cultivated in the study area (Reyes-García et al., 2014). This same criterion was used to select three modern varieties cultivated in the study area. Later, we used this information to generate a knowledge exercise in order to evaluate campesino and migrant gardeners' knowledge of landraces and modern varieties (details below). In this study, we defined a "local landrace" as a crop variety that has been continuously cultivated by farmers for more than one generation (30 years or more) in the area (Calvet-Mir et al., 2012).

2.2.2. Knowledge exercises and surveys of homegarden tenders

We applied knowledge exercises (Newing, 2011) to a total of 132 gardeners, including 83 campesinos (82 women; 1 man) and 49 migrants (46 women; 3 men) to examine knowledge of landraces and modern varieties. We adapted the approach of (Reyes-García et al., 2014), including questions on the three landraces and the three modern varieties identified with seedkeepers. The exercise considered 30 questions (5 questions x 6 varieties = 30) which involved: (1) Identification of the variety by showing the farmer the seed; (2) Indication of the variety's cultivation status at the time of exercise; (3) If the variety has been cultivated in previous years; (4) Response about the management of the variety; and (5) Response about the use of the variety (i.e., nourishment, medicine, ornamental, and ritual). We used the answers to the 15 questions about landraces to generate a "knowledge score on landraces" and the 15 questions about modern varieties to generate a "knowledge score on modern varieties" (Reyes-García et al., 2014). Each of the 30 questions had a value of 1 if the answer was correct; therefore, the maximum knowledge score per general seed classification was 15. An answer was considered correct when it coincided with that given by local farmers considered "expert gardeners" (determined before during interviews with seedkeepers). Finally, we applied a questionnaire to each of the 132 gardeners (Schneider, 2010) to examine social-ecological filters that may be influencing knowledge of agrobiodiversity (Table 1).

2.3. Data analysis

We measured the strength of linear association between the knowledge score of landraces and the knowledge score of modern varieties computing point-wise Pearson correlations. We then assessed differences in the knowledge scores of agrobiodiversity (a. general -landraces and modern together-, b. landraces, and c. modern varieties) between campesinos and migrants, using Mann-Whitney-Wilcoxon U rank-based tests (Quinn and Keough, 2002). We later used linear mixed-effects models to assess the association of knowledge score of agrobiodiversity with *a priori* defined social-ecological filters (Table 1). We used mixed-effects models because they integrate both fixed effects, explaining variation in the response variable, and random effects, which serve as an additional error term to account for correlations among observations within the same group (Quinn and Keough, 2002). We explored models with the knowledge scores of agrobiodiversity as a response to social-ecological filters shown in Table 1, as fixed effects, after reducing multicollinearity. Because of uneven distances among households, we used "locality" as a random effect in all models.

To obtain the best models on the knowledge score of agrobiodiversity, we created a set of models based on their weights (wi) and the precision of the estimated coefficients, using an approximation based on information theory. To assess the strength of the evidence for each tested model, we calculated the value of the Akaike Information Criterion (AIC) for small sample sizes (AICc) and model weight (w_i). We used model weights to calculate evidence ratios (ER) and compare the relative support of different models, including the null expectation (Burnham and Anderson, 2002). Since all these quantitative analyses may not capture the complexity of the agricultural knowledge system, we used the information derived from semi-structured interviews to interpret and discuss the quantitative results in broader historical and contemporary contexts (Barreau et al., 2016, 2019).

Table 1
Social-ecological filters used to examine knowledge of agrobiodiversity in the southern Andes.

Social-ecological filter	Description	Type of variable
Gardener age	Age of the gardener	Discrete (years old)
Mentor	Main source of learning on how to garden	Categorical (self-taught, family, local people, courses)
Seed source	Main source of seed acquisition	Categorical (self-production, purchase, exchange)
Seed exchange	Participation in seed exchanges ("trafkintu")	Categorical (0 = no, 1 = yes)
Subsidies	Receives subsidies from State agricultural extension agencies	Categorical (0 = no, 1 = yes)
Gardener origin	Campesino or migrant	Categorical (0 = campesino, 1 = migrant)
Starting age	Age when the participant started gardening	Discrete (years old)
Commercialization	Percentage of the total production that is commercialized	Discrete (scale from 1 to 10)
Self-consumption	Percentage of the total production that is consumed by the family	Discrete (scale from 1 to 10)

3. Results

From the semi-structured interviews with expert gardeners (seedkeepers), we identified and selected well-known (Scientific name: *Phaseolus coccineus*, English name: Runner Bean, Local name: poroto pallar), moderately known (*Vicia faba*, Purple Fava Bean, haba morada), and little-known (*Lathyrus sativus*, Grass Pea, chícharo) landraces. We also identified the following modern varieties: well-known (*Cucumis sativus*, Cucumber, pepino), moderately known (*Physalis* sp., Golden Berry, fisalis), and little-known (*Brassica oleracea* var. *sabellica*, Kale, kale).

From the perspective of seedkeepers, the three landraces were identified and selected, for the knowledge exercises, based on their cultural and nutritional significance as well as their adaptive capacities to temperate climate and Andean mountainous soils and landscapes. Among the selected landraces, the well-known was the Runner Bean, which is considered culturally important and key to various year-round gastronomic traditions, including soups, stews, and salads. Seedkeepers indicated that after sowing it, this landrace can last for two growing seasons, ensuring a steady harvest over two years without annual replanting. Nutritionally, it is locally consumed as an essential source of protein, fiber, vitamins, and it is considered as a good source of antioxidants, making it a valuable component of the local diet both in terms of nutrition and cultural heritage. The moderately known was the Purple Fava Bean, which is a legume that, according to seedkeepers, is experiencing a decline in regional consumption, but renowned for its vibrant color and satiating properties. Despite its lower yield (2–3 seeds per pod) and the larger cultivation area required, it remains significant due to its nutritional benefits and cultural value. However, it requires a prolonged cooking time, increasing the demand for firewood. The little-known Grass Pea was the rarest among the studied landraces. Known by seedkeepers for its resilience to harsh environmental conditions such as droughts, frosts, and heavy rains, this legume was traditionally used in the iconic local dish known as '*miyokin*', serving a similar role to bread. Despite its acknowledged nutritional benefits and value as a food heritage, its cultivation is locally considered to be declining due to reduced land property sizes.

On the other hand, modern varieties were selected due to their nutritional additionality to local diets, market and consumption trends, and their agronomic characteristics. Compared to landraces, modern varieties like Cucumber, Golden Berry, and Kale were generally considered to have lower cultural importance and nutritional qualities, particularly in terms of protein, carbohydrate, and micronutrient content. Cucumber was associated with the arrival of greenhouses to the region, increasing its availability for fresh salad. Nonetheless, these crops are increasingly present in local markets and homegardens, reflecting changing dietary preferences and market demands.

Through the knowledge exercises, we found that gardeners with more proficient knowledge of landraces were more knowledgeable of modern varieties, as shown by the strong positive correlation between knowledge of landraces and the knowledge of modern varieties (Fig. 1a). The general knowledge of agrobiodiversity (Mann-Whitney-Wilcoxon *U* test, W = 2477.5, $p = 0.03$) and the knowledge of landraces (W = 3057, $p = 7.76\text{e-}07$) was higher for campesinos than migrants, but the knowledge of modern varieties showed no differences between these two types of farmers (W = 1656, $p = 0.09$; Fig. 1b).

3.1. How social-ecological filters influence the knowledge of agrobiodiversity?

The models with the highest support (Δ AIC ≤2) for the general knowledge of agrobiodiversity (i.e., knowledge scores for both landraces and modern varieties together) contained four to eight social-ecological filters (Table 2a). Model selection showed that knowledge of agrobiodiversity was relatively higher in gardeners with a seed source characterized chiefly by self-production and exchanges, and in those who actively participate in seed exchanges events or "trafkintus" (Fig. 2a; Table 3a shows estimated βs for significant social-ecological filters).

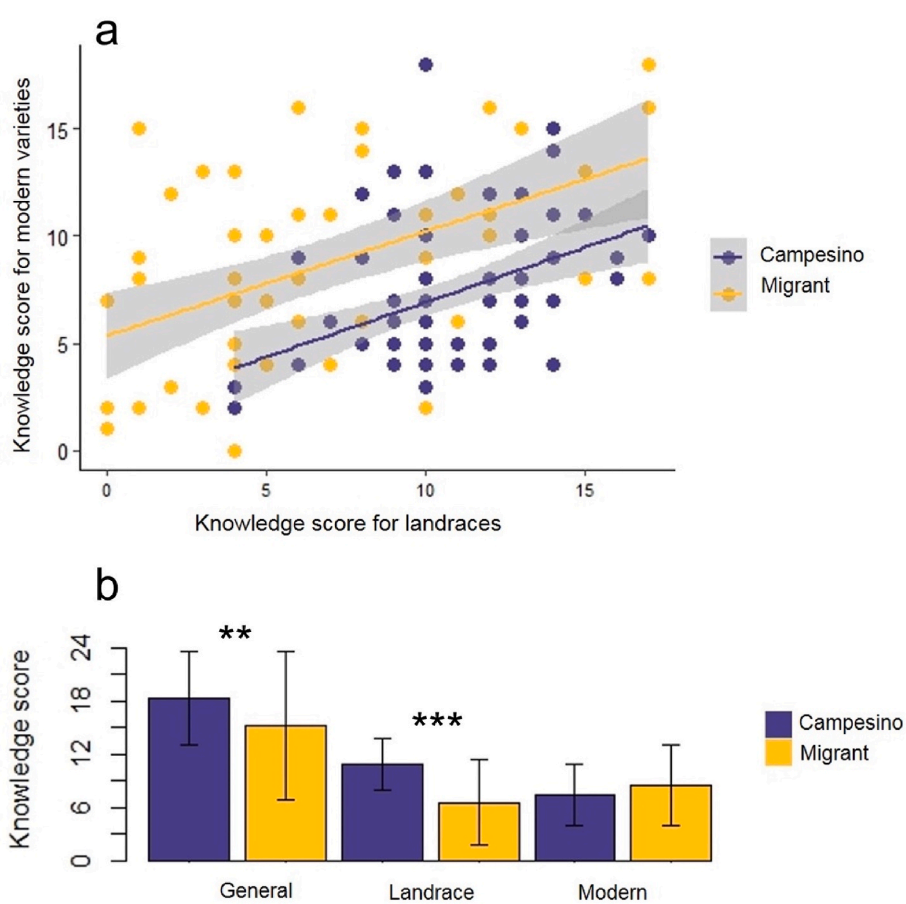

Fig. 1. (a). Estimated association between knowledge score for landraces and knowledge score for modern varieties of campesino (purple dots) and migrants (yellow dots) in the southern Andes. (b). Differences between campesinos and migrants in the knowledge scores of agrobiodiversity (general -landraces and modern together-, landraces, and modern varieties). Asterisks show statistical significance: ** = $p < 0.05$, *** = $p < 0.01$. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Ranking of models for knowledge of agrobiodiversity: (a) general (landraces and modern varieties together), (b) landraces, and (c) modern varieties, as a function of social-ecological filters. Locality was a random term in all tested models.[a] Number of parameters estimated;[b] Difference in AICc values between each model and the lowest AICc model;[c] AICc model weight;[d] AICc cummulative weight;[e] Log likelihood.

Model structure	K[a]	AICc	ΔAIC[b]	Wi[c]	Cum Wi[d]	LL[e]
a) General						
Gardener age + Mentor + Seed source + Seed exchange	11	876.61	0.00	0.50	0.50	−426.20
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Self-consumption	15	878.57	1.96	0.19	0.68	−422.21
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Commercialization	15	878.90	2.29	0.16	0.84	−422.38
Gardener age + Subsidies + Mentor + Seed source + Seed exchange	12	878.93	2.32	0.16	1.00	−426.15
Gardener age + Subsidies + Starting age + Seed exchange	7	890.80	14.19	0.00	1.00	−437.95
b) Landraces						
Gardener age + Mentor + Seed source + Seed exchange	11	720.44	0.00	0.75	0.75	−348.12
Gardener age + Subsidies + Mentor + Seed source + Seed exchange	12	722.78	2.33	0.23	0.98	−348.08
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Self-consumption	15	729.10	8.65	0.01	0.99	−347.48
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Commercialization	15	729.32	8.88	0.01	1.00	−347.59
Gardener origin + Subsidies + Mentor + Seed source + Gardener age	12	735.78	15.34	0.00	1.00	−354.58
c) Modern varieties						
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Self-consumption	15	720.19	0.00	0.31	0.31	−343.03
Gardener origin + Gardener age + Subsidies + Starting age + Mentor + Seed source + Seed exchange + Commercialization	15	720.27	0.08	0.30	0.61	−343.06
Gardener age + Mentor + Seed source + Seed exchange	11	721.30	1.11	0.18	0.80	−348.55
Gardener origin + Gardener age + Starting age + Mentor + Seed exchange	10	723.23	3.04	0.07	0.86	−350.71
Gardener age + Subsidies + Mentor + Seed source + Seed exchange	12	723.24	3.05	0.07	0.93	−348.31

The models with the highest support for knowledge of landraces contained four social-ecological filters (Table 2b). Model selection showed that knowledge of landraces was positively correlated with gardeners' age (Fig. 2b). Best models also supported that knowledge of landraces was relatively lower in gardeners who purchase seeds as their main source of agrobiodiversity but was higher in those who actively exchanged seeds with other gardeners in the area (Fig. 2b; Table 3b).

Finally, the models with the highest support for knowledge of modern varieties contained eight to four social-ecological filters (Table 2c). Model selection showed that knowledge of modern varieties was higher in migrants than in campesino gardeners (Fig. 2c). Best models also supported that knowledge of modern varieties was negatively correlated with starting age (i.e., participants that started gardening younger had a higher knowledge of modern varieties; Fig. 2c). Again, knowledge of modern varieties was relatively higher in those gardeners who actively participated in seed exchanges events (Fig. 2c; Table 3c).

4. Discussion

Social-ecological systems are being resilient when they have the capacity of incorporating new information whilst maintaining their identity without undergoing a major shift in their basic structures and functions (Berkes, 2017; Walker and Salt, 2006). The broad novelty of our contribution lies in its revelation of a potential coexistence between traditional landrace knowledge and modern variety knowledge among farmers. This finding suggests that small-scale farming systems may exhibit resilience by not only maintaining knowledge of landraces but also incorporating knowledge related to modern varieties. Moreover, the study sheds light on the intricate web of social-ecological filters that influence and shape agrobiodiversity knowledge, emphasizing the non-random processes that underpin distinct knowledge patterns among farmers in the southern Andes and beyond (Cortés et al., 2023; Ibarra et al., 2021b). This study, conducted in an Important Agricultural Heritage System (IAHS) and Global Biodiversity Hotspot, extends previous research on how small-scale farming systems learn and endure by incorporating new information (i.e., social-ecological resilience; (Darnhofer et al., 2016), but also "archiving" the one that is no longer useful.

We based our work on examining the knowledge of agrobiodiversity, particularly seeds (i.e., seed identification, variety's current and previous cultivation status, management of the variety, and use of variety), by Indigenous and non-Indigenous campesinos and migrant gardeners. As we discussed below, seeds are important for nurturing resilience as agrobiodiversity knowledge has direct links to sustainable livelihoods and food sovereignty (Kansiime and Mastenbroek, 2016; Montúfar and Ayala, 2019).

4.1. The influence of social-ecological filters on the knowledge of agrobiodiversity

4.1.1. The importance of local fabrics, seed exchanges, and gardener's age

Our results show that participation in seed exchanges or "trafkintu" is an important social-ecological filter for increasing the knowledge of agrobiodiversity, as farmers who actively participated in seed exchanges

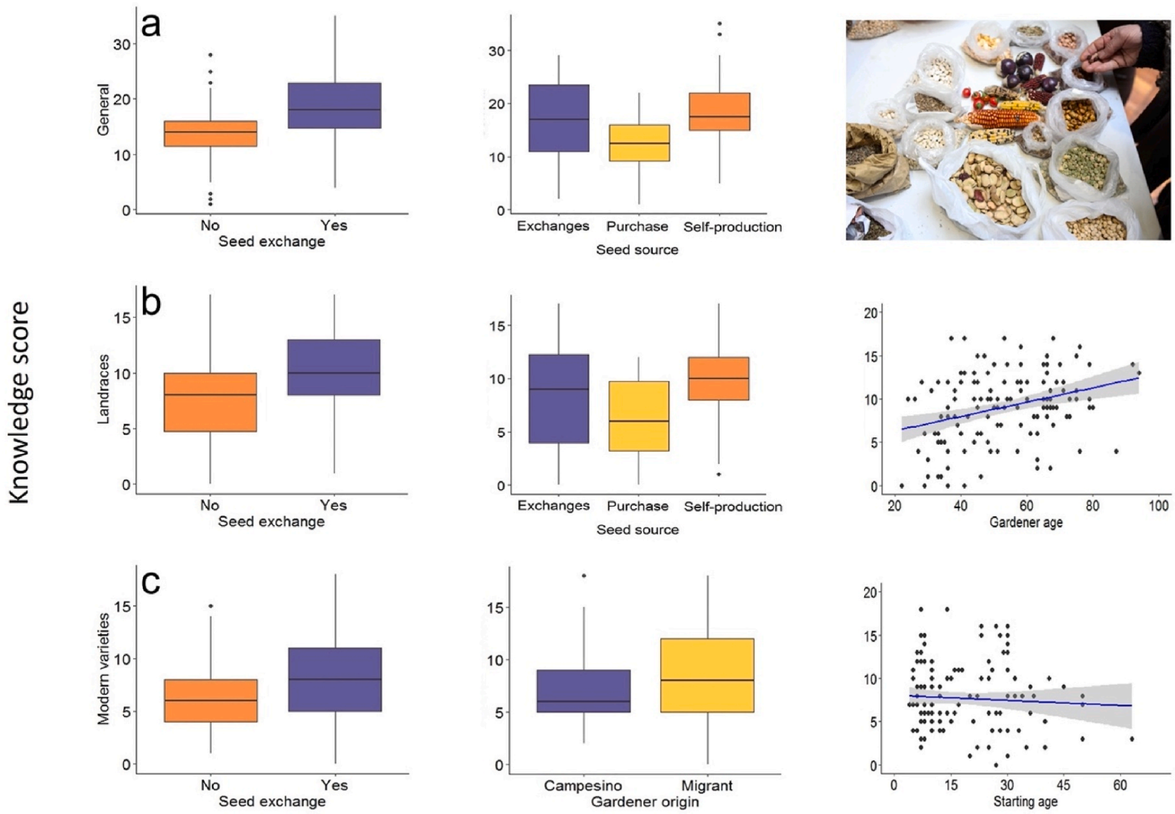

Fig. 2. (a). Response of knowledge scores for general agrobiodiversity (landraces and modern varieties together) to the most influential social-ecological filters, including participation in seed exchanges and seed source. (b). Response of knowledge scores for landraces to the most influential social-ecological filters, including participation in seed exchanges, seed source, and gardener's age. (c). Response of knowledge scores for modern varieties to the most influential social-ecological filters, gardener origin, and starting age.

showed a higher knowledge of agrobiodiversity in general, as well as of landraces and modern varieties. Seed exchanges or "trafkintu" not only refer to the physical act of exchanging seeds, but it is a social process accompanied by an exchange of cultural information and knowledge, acting as well as an act of trust and bonding (Pautasso et al., 2013).

The diversity of seeds and exchange networks based on reciprocity, as well as the productive activities of the rural households, were identified as key assets for nurturing social-ecological resilience in this IAHS. Seed diversity and networks have survived and renewed themselves through time, being both very dynamic. Agricultural exchange networks are recognized as a crucial factor that promotes the development of food sovereignty and social innovation (Parraguez-Vergara et al., 2018). Social innovation, which is generally associated as a factor in building resilience, emerges when the physical act of exchanging seeds is intertwined with the interpersonal sharing of knowledge that helps to create new social relations while contesting predominant industrial agricultural systems. (Balázs and Aistara, 2018). Indeed, seed exchanges in the southern Andes, which have a Mapuche Indigenous origin, have historically transitioned and transformed to persist in the present day, with an emphasis during periods of struggles for the defense of territories, natural resources, and common goods (M. I. Ibarra et al., 2023b; Shiva, 2016).

Regarding the age of farmers, our results indicate that a higher age among them correlates with a greater knowledge of local varieties. This aligns with findings from Carchi, Chimborazo, and Loja in Ecuador, where a study spanning over 30 years on potato variety conservation revealed that older farmers maintained local varieties, while young people, upon migrating to urban centers, usually lost interest in the matter (Monteros-Altamirano, 2018). This result highlights how the elderly people play a pivotal role in food sovereignty and the safeguarding of associated biocultural heritage; however, it also indicates that family and intergenerational involvement, may be a critical factor for seed conservation (Ibarra et al., 2021a; Lastarria-Cornhiel, 2006).

Despite the advent of modern seeds, seeds that have cultural significance are still cultivated, saved, and exchanged among gardeners, such as Mapuche maize and various varieties of broad beans, peas, and beans. Even though they were not domesticated in these latitudes, crops such as beans and maize have archaeological records of more than 1300 and 600 years in these southern territories, respectively (Campbell et al., 2018). Many of the landraces of these and other crops used today come from previous family generations (usually female ancestries like mothers, grandmothers, and aunts) and are recovered from family, community members, and friends in case they are lost. These results are consistent with similar experiences reported on seed saving in countries such as India (Hazareesingh, 2021) and Kenya, where older women are considered key actors for public agricultural policies while playing a crucial role in the maintenance of landraces (Diiro et al., 2018).

4.1.2. Do migrants have a role in building social-ecological resilience?

Our study shows that knowledge of modern seeds was higher in lifestyle migrants, and this may be associated with the fact that many of them have mixed or hybrid agricultural knowledge, higher access to information and connectivity, many times a relatively greater purchasing capacity which can translate to access to foreign or imported seeds (Benson and O'Reilly, 2009). Lifestyle migration refers to individuals and families who sought to uproot themselves from urban landscapes and settle in rural settings. As lifestyle migrants have increasingly arrived in rural landscapes globally (especially after Covid-19), they have brought with them not just their desires of a simpler existence, but also a diverse array of experiences and knowledge (Marchant, 2017). In other mountain systems around the world such as the Sierra Nevada, García-del-Amo (García-del-Amo et al., 2022) pointed out that lifestyle

Table 3
Beta estimates of social-ecological filters present in the first ranked models of knowledge of agrobiodiversity in the southern Andes.

Social-ecological filter		Estimate	Standard error	P-value	Significance[a]
a) General					
Intercept		227.02	0.35	0.00	***
Gardener age		0.05	0.09	0.55	
Mentor	Self-taught	−0.26	0.18	0.15	
	Courses	−0.17	0.23	0.44	
	Family	−0.07	0.18	0.69	
	Local people	−0.33	0.20	0.10	,
Seed source	Purchase/exchanges	0.26	0.34	0.43	
	Self-production	0.32	0.07	0.00	***
	Exchanges	0.32	0.10	0.00	**
Seed exchange		0.27	0.05	0.00	***
b) Landraces					
Intercept		140.04	0.58	0.02	*
Gardener age		0.27	0.11	0.02	*
Mentor	Self-taught	−0.10	0.28	0.73	
	Courses	−0.21	0.34	0.53	
	Family	0.32	0.27	0.24	
	Local people	−0.13	0.30	0.67	
Seed source	Purchase	−0.94	0.38	0.01	*
	Self-production	−0.58	0.37	0.12	
	Source exchanges	−0.46	0.39	0.23	
Seed exchange		0.24	0.07	0.00	***
c) Modern varieties					
Intercept		188.58	0.78	0.02	*
Gardener origin		0.44	0.16	0.00	**
Gardener age		0.01	0.14	0.94	
Subsidies		0.02	0.10	0.83	
Starting age		−0.16	0.08	0.04	*
Mentor	Self-taught	−0.31	0.23	0.18	
	Courses	−0.07	0.29	0.80	
	Family	−0.25	0.24	0.30	
	Local people	−0.41	0.26	0.12	
Seed source	Purchase	0.37	0.51	0.47	
	Self-production	0.70	0.50	0.16	
	Source exchanges	0.57	0.51	0.27	
Seed exchange		0.24	0.08	0.00	**
Self-consumption		−0.03	0.02	0.12	

[a] Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 ',' 0.1 '' 1.

migrants have acted as a revitalizing factor for associated local agricultural knowledge. They have contributed, for example, to the reintroduction of local varieties that were locally lost (e.g., "pico de pájaro lettuce" in the High Alpujarra). These migrants usually have access to global information networks, and thus they have access to a wealth of knowledge about modern seeds, crop varieties, and innovative farming techniques. However, challenges are not absent from this phenomenon. The introduction of foreign crops and modern seeds has raised questions about their sustainability in the local ecosystem. It is also important to carefully assess the potential unforeseen consequences of lifestyle migration, such as gentrification processes that might alter the social dynamics within local communities (Perlik, 2011). While the incorporation of diverse knowledge streams has the potential to enhance local food sovereignty (Ibarra et al., 2019b), numerous historical and present-day developments linked to the introduction of 'modern practices' (e.g., chemical fertilizers) into traditional agricultural systems could have adverse effects on the livelihood resilience of small-scale farmers, even leading to the homogenization of traditional agricultural and food systems (Barreau et al., 2019). Our results are in line with what Perales et al., (Perales et al., 2005; Nazarea, 2006; Nazarea, 2006, 2006) have pointed out, indicating that the connection between biocultural identity and local memory determines the maintenance of landraces being actively cultivated *in vivo* in local gardens (not just in seed banks). Therefore, exchange networks involving diverse and multiple local actors and migrants are crucial for the resilience of the system. The latter is because a low level of knowledge, and thus a limited adoption of local varieties by migrant gardeners could compromise the survival of landraces in the medium and long term.

Nowadays, where the local is increasingly embedded within global processes, the substitution of foods and the incorporation of new crops and preparations through 'inter-ethnic' contact is expected (Jamal, 2003). Nevertheless, the memory expressed in Indigenous and campesino agriculture is generally a source of identity and autonomy that resists to be substituted for something else. As such, food growing, preparation, and consumption are social spaces where local, regional, and global powers interact with local agency (Monterrubio-Solís et al., 2023). Social-ecological resilience depends on the farmer's ability to choose seeds that will sustain future seasons in enough quantity according to the household needs. Therefore, resilience takes de form of conserving local varieties, but also letting go the ones that no longer serve under social-ecological drivers of change.

5. Recommendations

In the endeavor to build social-ecological resilience amidst global changes, we provide a few interweaving elements to safeguard landraces and their associated knowledge.

First, it is critically important to disseminate knowledge of landraces. A deliberate effort to disseminate awareness regarding a diverse spectrum of locally nurtured seeds is underway in many locations (Porcuna-Ferrer et al., 2020; Vernooy et al., 2017). This endeavor serves as a bulwark, maintaining distinct crops and nurturing biodiversity. Second, recognizing and strengthening community endeavors as commending the communities' steadfast dedication to maintaining landraces emerges as a critical aspect (Cid Aguayo and Latta, 2015; Gutiérrez Escobar and Fitting, 2016; Peschard and Randeria, 2020). This acknowledgment not only underscores their contributions but also elevates their role in nurturing these unique crops; the role of elderly people and seed curators needs to be honored (Ibarra et al., 2021a; Nazarea, 2006; Peralta Celis and Thomet Isla, 2011). Third, it is required to understand and follow Indigenous and local protocols. These guidelines provide a framework that will direct the stewardship of landraces and traditional practices. Acquiring an understanding of and disseminating these guidelines ensures their universal benefit, fostering resilience within the realm of agricultural practices and local empowerment and accountability (J. T. Ibarra et al., 2023a). Fourth, a global world under rapid change demands embracing migration dynamics. Counterintuitively, the migration of individuals from urban to rural settings may hold the potential to contribute to the conservation of local crops (García-del-Amo et al., 2022). The comprehension of this migratory trend can harness its latent potential to sustain landraces. Fifth, and finally, synergistic collaborations between Indigenous peoples, local communities, scientists, and seed activists are needed for building social-ecological resilience (J. T. Ibarra et al., 2023a); both migrant and resident populations within rural contexts bear a shared responsibility to protect this biocultural heritage. By fostering collaborative efforts, we can strengthen time-honored farming methodologies, and the use and maintenance of landraces and their associated knowledge, thereby nurturing a foundation of social-ecological resilience for the present and the future.

CRediT authorship contribution statement

José Tomás Ibarra: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Julián Caviedes:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Constanza**

Monterrubio-Solís: Writing – review & editing, Methodology, Investigation. **Antonia Barreau:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Carla Marchant:** Writing – review & editing, Project administration, Conceptualization.

Declaration of competing interest

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Data availability

Data will be made available on request.

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