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Family farming systems: An index-based approach to the drivers of agroecological principles in the southern Andes

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ABSTRACT

Global social-ecological crises call for the identification and promotion of resilient agrifood systems. Agroecology can help addressing these challenges by fostering high levels of diversity and climate resilience. The application of agroecological principles (i.e. social-ecological processes translated into practices with positive effects on the conservation, stability and resilience of agriculture), increases systems' response capacity and ability to adapt to crises. Agroecology has its roots in indigenous agriculture but social-ecological filters (i.e. human-nature factors that remove or reinforce agroecological practices) may be, at times, shifting away these systems from agroecological principles. The dynamism of territories has prompted the arrival of new actors to rural areas such as lifestyle migrants. In this study, we assess the extent to which agroecological principles are present in family farming in the southern Andes and identify factors that can act as "social-ecological filters" of management practices, affecting the level of agroecology in these systems. We applied questionnaires to 80 gardeners (40 campesinos and 40 migrants), asking about 35 management practices and their socio-demographic profiles. We developed an Index of Agroecological Principles (IAP) to estimate the presence/absence of management practices that contribute to seven agroecological principles (four biological and three sociocultural). Most principles showed a presence over 0.5 (50%). We found a positive relationship between biological and cultural principles ($r = 0.56$; $p < 0.01$). Biodiversity was the principle with the highest presence (0.72 ± 0.01). The value of the IAP was higher for indigenous and non-indigenous campesinos (4.5 ± 0.1; ß $= 4.27$) than for migrants (3.9 ± 0.12; ß $= -0.4$). The origin of the gardener, the age of the homegarden and the size of the farm, were the most influential social-ecological filters that selectively remove or reinforce agroecological practices in homegardens. We discuss the potential of an Index of Agroecological Principles in homegarden management for strengthening agroecology and resilience to social-ecological changes in a Global Biodiversity Hotspot and beyond.

1. Introduction

Climate change has increased the frequency of extreme events such as droughts, floods, variations in precipitation and heat waves, with a negative impact on agrifood systems around the world (IPCC, 2021; Leippert et al., 2020). In addition to climate change, other environmental problems synthesized as global change (IPBES, 2019) are threatening human wellbeing in multiple ways. Faced with these rapid changes, agroecology is an alternative for sustainable production, favor biodiversity conservation, strengthen social cohesion and promote adaptation to climate change (Anderson et al., 2019; Baker et al., 2019; Carof et al., 2022). This type of agriculture fosters high levels of diversity, ensures a continuous supply of ecosystem services and produces healthy food whilst also being conducive to local autonomy and sustainable jobs (Altieri, 1983; Timmermann and Félix, 2015). Agroecology has its roots in traditional family farming systems (Toledo, 1990).

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Table 1
Agroecological principles selected for evaluation in homegardens of the southern Andes.

Principle 1	Energy and material cycles: minimize the loss of energy, water, nutrients and genetic resources, improving the conservation and regeneration of the soil and water resources and agrobiodiversity.
Principle 2	Soil quality: provide the most favorable soil conditions for plant growth, particularly by incorporating organic material and increasing the biological activity of the soil.
Principle 3	Biodiversity: diversify the species and genetic resources in the agroecosystem over time, space and landscape.
Principle 4	Biological interactions: improve beneficial biological interactions and synergies between the components of the agrobiodiversity, promoting ecological processes and services.
Principle 5	Knowledge transmission: ensure and facilitate the intergenerational and intragenerational transfer of knowledge.
Principle 6	Sociocultural connections: boost sociocultural connections by strengthening campesino-campesino dialogue, family conversations and local networks.
Principle 7	Productive and financial autonomy: guarantee access to the market and autonomy, avoiding dependence on single crops or products and external subsidies and boosting the use of alternative markets and local producer–consumer cycles.

Indigenous and non-indigenous campesino communities have developed complex bodies of knowledge, practices and beliefs about the functioning and interaction of the components of the soil, climate, vegetation and animals as well as community production strategies and agrifood self-sufficiency (Guzmán Casado et al., 2000;Nazarea, 2006).

Agroecology integrates biological (e.g. the conservation and restoration of the systems' components such as soil, water and biodiversity) and sociocultural (e.g. the farm income, knowledge transmission, inputs efficiency, strategies of collaboration) principles in line with the ecological, socioeconomic and cultural context (Francis et al., 2003; Rivera-Ferre, 2018). This implies a diversification of practices that will have different effects on the functioning of the farm, the farmer, the family and the community (Nicholls et al., 2016). Depending on how a particular agroecological practice is applied and complemented, it can contribute to more than one of these biological and sociocultural principles and, therefore, to a more resilient agriculture (Wezel et al., 2009). For example, intercropping is used to improve systems' biodiversity, contributing to agroecological principles such as energy cycles, soil quality and biological interactions (three biological principles of agroecology; Vandermeer, 1989; Table 1). Similarly, the practice of exchanging seeds strengthens a community's social cohesion and boosts family autonomy (two sociocultural principles; Kapgen and Roudart, 2020).

Family farming systems commonly integrate different production units within a household's land. One of these units are homegardens, which are used to produce seeds, herbaceous plants, flowers, shrubs and trees and even to keep animals (Eyzaguirre and Linares, 2010; Galluzzi et al., 2010). Farmers are constantly adapting to social-ecological changes in their territories, which include variations in climate, public policy and market forces (Monterrubio-Solís et al., 2023), water scarcity and arrival of new technologies (Altieri et al., 2015) as well as shifts in local political-economic contexts (e.g. urban exodus to the countryside; Ibarra et al., 2019). These changes are often known as "social-ecological filters", which are defined as coupled human-nature factors that remove or reinforce agroecological practices and, therefore, modify the extent to which agroecological principles are present in the farming systems (Ibarra et al. 2021). For example, in Vietnamese homegardens, cultural

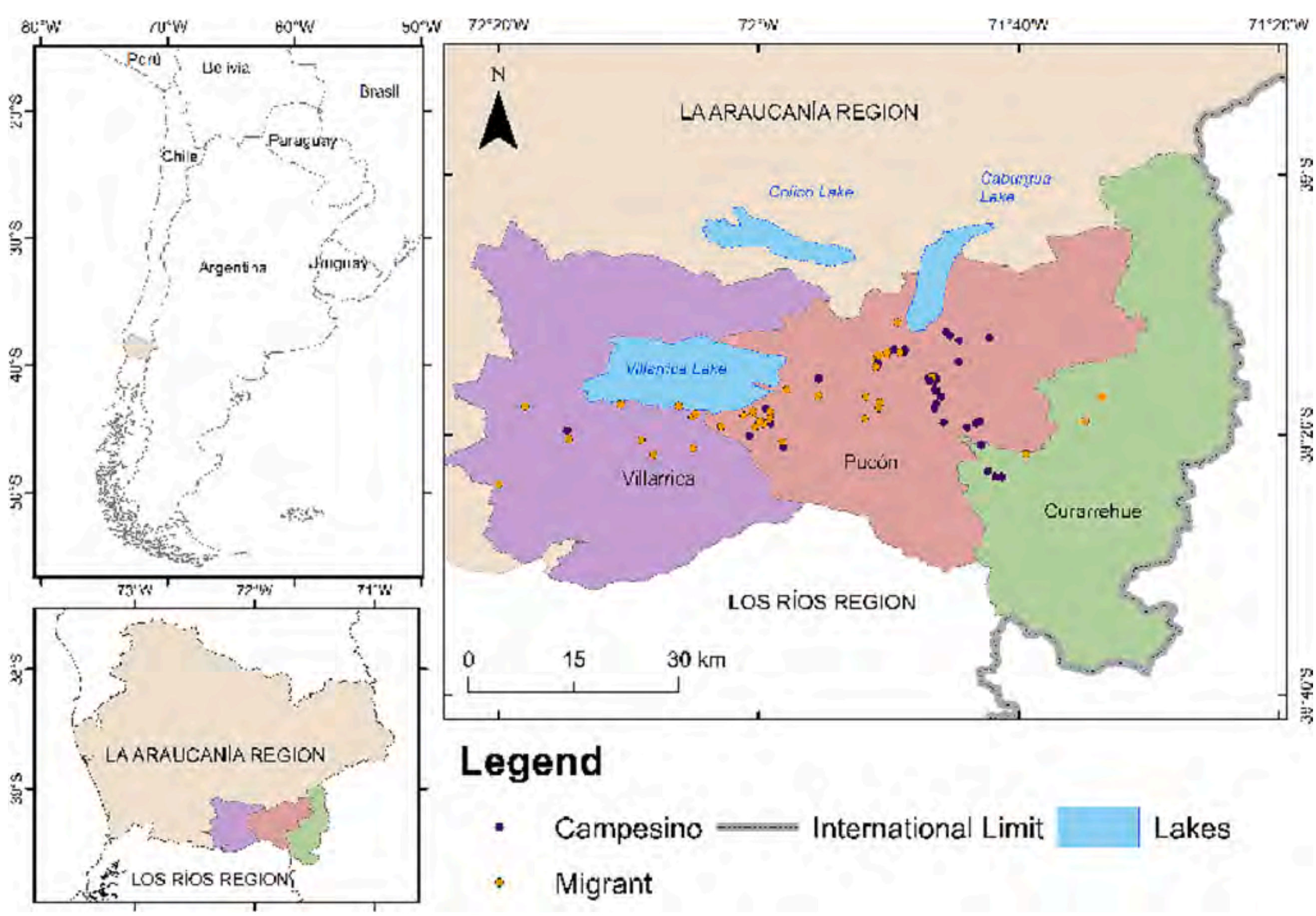

Fig. 1. Study area within the Villarrica watershed (39°S 71°W) in Andean temperate landscapes, southern Chile. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

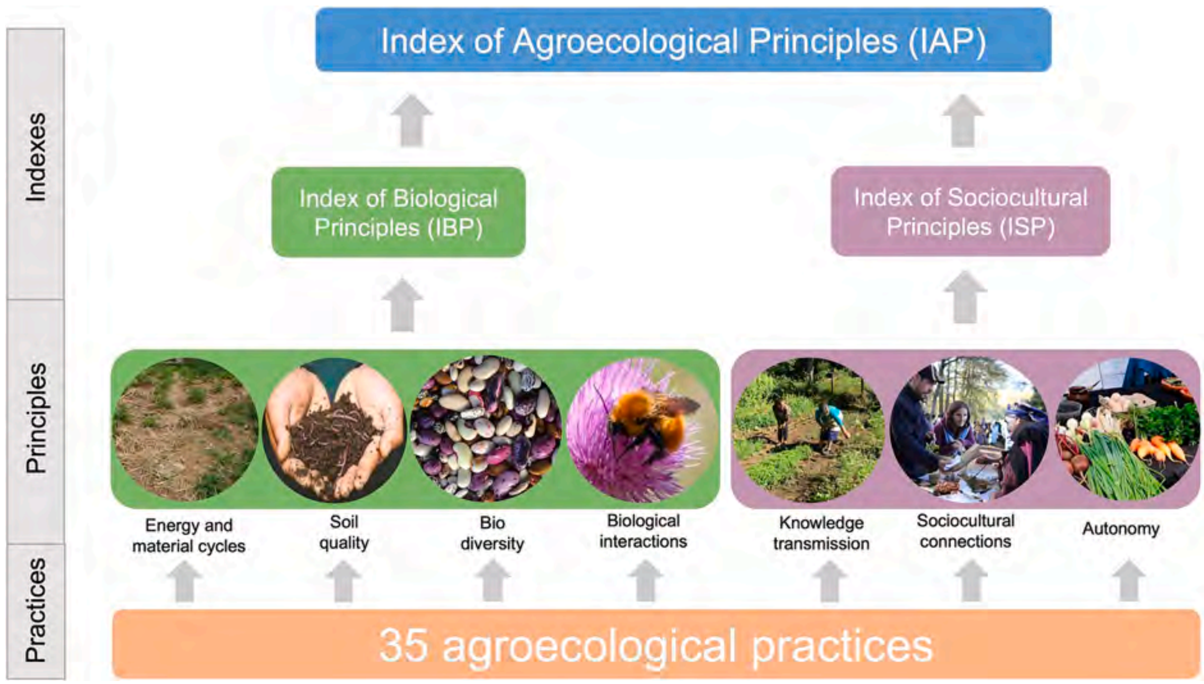

Fig. 2. Steps for the construction of an index of agroecological principles. See Appendix for more information about the practices associated with each Index. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

origin acts as a filter for local varieties and the related knowledge (Trinh et al., 2003) while, in Benin, Africa, the gardener's age and years of experience in tending a homegarden can also affect practices and the management of agrobiodiversity (Avouhou et al., 2012; Idohou et al., 2014). Further, rural territories are changing socio-demographically and are ever more connected, accentuating the phenomenon of city-countryside migration (United Nations, 2019). As a result, many rural territories are inhabited by people of different origins. In Guatemala, for example, indigenous and mixed-race (Spanish/indigenous) farmers live in the same territory and employ similar agricultural practices (Azurdia and Leiva, 2010).

There is no information about the changes taking place in management practices in homegardens in southern Chile, a territory identified as a Global Biodiversity Hotspot (Myers et al., 2000) and a Nationally Important Agricultural Heritage System (FAO, 2014). In this study, we (i) evaluate the presence of agroecological practices and principles in the homegardens of indigenous and non-indigenous campesinos and migrants, and (ii) examine the relation between social-ecological filters and the presence of agroecological principles in the southern Andes. We predict that the socio-demographic profiles and the attributes of homegardens act as social-ecological filters and may, therefore, influence the presence of agroecological practices at both the biological and sociocultural levels (Boonstra et al., 2016; Ibarra et al., 2021). For the purposes of this analysis, we created an Index of Agroecological Principles that, as shown in our study, could serve to guide and strengthen processes of transition to agroecological systems of production in both the southern Andes and other small-scale farming systems elsewhere in the world.

2. Methods

2.1. Study area and sample design

The study was carried out in the watershed of Lake Mallolafken (or Lake Villarrica) in 29 randomly selected localities in the Villarrica, Pucón and Curarrehue municipal districts of Chile's La Araucanía Region (Fig. 1). These municipal districts are located in the Andean part of Wallmapu, or Mapuche country, in temperate landscapes. This area has a short dry season (less than four months) and is highly vulnerable to climate change (Borsdorf et al., 2014; Parraguez-Vergara et al., 2016). Historically, these territories have been occupied by the Mapuche people-nation, who have developed a system of family farming that is essential for local livelihoods and makes a significant contribution to food supply, the economy, education and family and community cohesion (Bengoa and Valenzuela, 1983). The area also has a high tourism development due to the complexity of the landscape and its scenic beauty, with old-growth forests, rivers, lakes, volcanoes, glaciers and mountains among its key elements. These attributes have attracted lifestyle migrants and, therefore, the population of these municipal districts is growing ahead of the national average (Instituto Nacional de Estadísticas, 2017; Marchant, 2017).

2.2. Study design

The study took homegardens and the gardener responsible for tending them (household) as the sample unit. Fieldwork was conducted between November 2020 and March 2021. The minimum number of homegardens to be studied was calculated considering a significance level of $\alpha = 0.05$ and t-value = 1.96 as the desired level of accuracy for α. Sample sizes were calculated for each of the three response variables considered in the analysis and the largest size was selected. Following the recommendations of Bartlett et al. (2001), and taking a 3% margin of error as acceptable for continuous response variables, the appropriate sample size was estimated to be 68 gardeners. Conservatively, it was decided to interview 80 gardeners (40 indigenous or non-indigenous campesinos and 40 lifestyle migrants), who were selected using a non-probabilistic snowball recruitment approach (Robinson, 2014). Indigenous and non-indigenous campesinos were treated as a single group because they were born, live and work in the same territory, have close contact and use similar farming methods, including traditional Mapuche practices (Ibarra et al., 2021). In contrast, lifestyle migrants moved from urban areas as adults in search of places with unique natural and cultural attributes and a better quality of life (Marchant, 2017; Zunino et al., 2016). They tend to be professionals, sometimes of overseas origin, with

Table 2
Social-ecological filters used to evaluate homegarden associations of agroecological principles in the southern Andes.

Social-ecological filter	Type of variable	Description	Justification	Country where reported	Reference
Gardener's age	Discrete	Age of gardener (years)	The number of species and local varieties managed is influenced by the age of the head of the household.	Benin	(Avouhou et al., 2012; Gbedomon et al., 2015)
Gardener's origin[a]	Binomial	1: Campesino 2: Migrant	Origin and cultural preferences determine the composition of the homegarden.	Vietnam; Chile	(Trinh et al., 2003; Ibarra et al., 2021)
Gardener's gender[a]	Binomial	1: Male 2: Female	Women are frequently considered seed guardians, associated with local knowledge.	Malawi; Benin	(Galluzzi et al., 2010; Avouhou et al., 2012; Kerr, 2014)
Gardener's experience[a]	Discrete	Number of years the person has been gardening	The gardener's experience can influence the number of species cultivated.	Benin	(Idohou et al., 2014)
Homegarden age[a]	Discrete	Years that the homegarden has been in the same spatial location	Older homegardens are more biodiverse (high species richness).	Benin	(Gbedomon et al., 2015)
Farm size[a]	Continuous	Size of the farm (ha)	The farm's size influences agricultural sustainability (economic, environmental and social aspects).	Chile; China; Ethiopia	(Abebe et al., 2013; Ren et al., 2019; Ibarra et al., 2021)

[a] Social-ecological filters retained for tests of homegarden associations after reducing collinearity (Pearson's r > 0.6).

paid work outside the agricultural sector, although many have incorporated agriculture into their lifestyles (O'Reilly and Benson, 2009).

The criteria for selecting a homegarden were that: (1) it was used for family consumption, and (2) it was at least two years old. Ahead of the fieldwork, the questionnaire was applied to three gardeners as a pilot to detect possible deficiencies.

2.3. Construction of the instrument

The literature was reviewed to identify the practices that contribute to seven agroecological principles in small-scale farming systems such as homegardens. Four biological and three sociocultural principles were included (Altieri, 2001; Altieri et al., 2015; Dumont et al., 2016; Kapgen and Roudart, 2020; Nicholls et al., 2016; Nicholls et al., 2020; Teixeira et al., 2018; Tessier et al., 2020; Mori, 2016). A quantitative instrument was then developed to evaluate the presence/absence of 35 agroecological practices (binary variables; Appendices, Table A.1) in each of the 80 homegardens in the southern Andes (Fig. 2).

2.4. Social-ecological filters: socio-demographic profiles and homegarden attributes

We conducted interviews structured with data about the socio-demographic profiles and attributes of the 80 homegardens visited, including the gardener's origin, age, experience and gender, homegarden's age and farm's size (area) (social-ecological filters; Table 2). The homegarden's spatial location (geographical coordinates) was recorded using GPS.

Through tours guided by the gardener, we evaluated the presence/absence of 35 agroecological practices in their homegardens. The gardener reported some practices while others were identified by the researchers (Appendices, Table A.1, Table A.2). The presence of a practice was indicated with a 1 and its absence as 0, except for six practices whose absence was considered a contribution (recorded as 1) and their presence decreased the agroecological principle (recorded as 0; Appendices, Table A.1).

2.5. Data analysis

Three indexes were created: an Index of Agroecological Principles (IAP) estimated based on the presence/absence of the 35 management practices that contribute to the seven agroecological principles described above. The IAP, in turn, comprises an Index of Biological Principles (IBP), estimated according to four of the IAP's principles and focusing on evaluation of the system's processes and ecological functions, and an Index of Sociocultural Principles (ISP), reflecting the other three principles and focusing on evaluation of the transmission of local knowledge and the strengthening of local communities (Fig. 2).

The IAP is constructed from three levels: practices, principles and indexes (Fig. 2). Each practice contributes to one or more principles. In some cases, the same practice can contribute simultaneously to a biological and a sociocultural principle (eight of the 35 practices).

The value of each principle (*Vpx*) was calculated by adding the value of each of the practices (a_m) (value = 0 or 1) contributing to it:

$$Vpx = a_m + a_{m+1} + a_{m+2} \cdots + a_n$$

Depending on the number of practices contributing to it, each principle had a different maximum value and, therefore, a different statistical weight. To correct the over-representation of a principle compared to another in calculating the IAP, the values obtained for each principle were standardized (*VpxE*), dividing them by their maximum value (Vpx_{max}):

$$VpxE = \frac{Vpx}{Vpx_{max}}$$

Once standardized, the seven principles were added up to obtain the value of the IAP:

$$\sum_{i=1}^{7} VpxE = Vpe_1 + Vpe_2 + Vpe_3 + \cdots + Vpe_7$$

Similarly, IBP and ISP were constructed by adding only the standardized principles associated to each of them (Fig. 2).

Generalized linear mixed-effects models (Zuur et al., 2009) were used with lmer (Bates et al., 2015) and AICcmodavy (Mazerolle, 2017) packages in version 4.0.4 of the R studio software (R Development Core Team, 2021). We opted for mixed-effects models because they integrate fixed effects that explain the response variable (indexes) and random effects, which serve as an additional error term to explain correlations between observations within the same group (Quinn and Keough, 2002). Models were fitted with the gamma distribution (or inverse Gaussian distribution).

We first tested the IBP-IPS relationship by regressing the values of IPB against IPS. Then, we examine de association between a response variable and independent variables. IBP, ISP and IAP models were examined as response variables, social-ecological filters as fixed effects (Table 2) and locality as the random effect. Collinearity was tested to reduce the number of social-ecological filters shown in Table 2. The gardener's age was discarded because of its strong correlation with gardener's experience (Spearman's r > 0.6), which was considered a more influential filter for analyzing the system's agroecological practices. Six social-ecological filters were then selected: the gardener's cultural origin (indigenous/non-indigenous campesino vs. migrant),

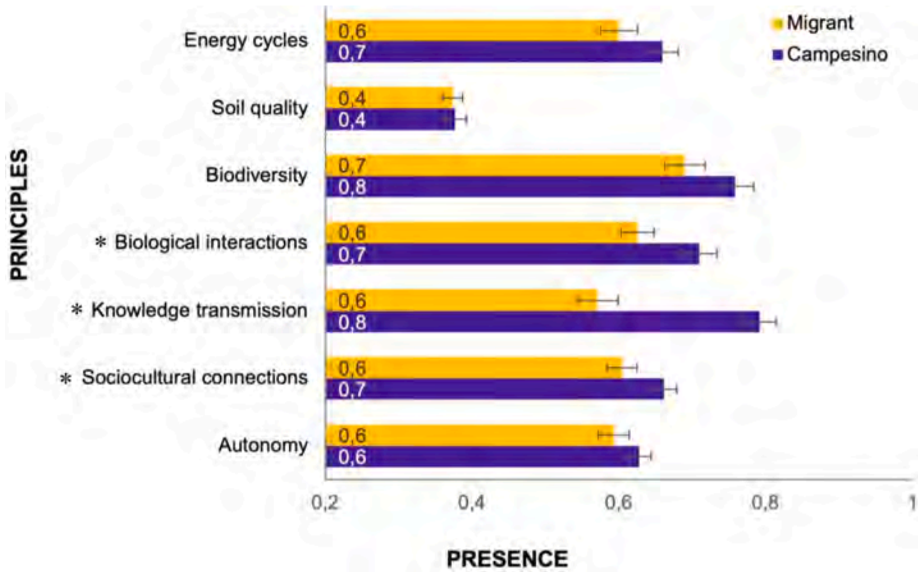

Fig. 3. Presence of seven principles evaluated by gardener origin. The bars indicate each principle's standard error. *Significant differences with a 95% confidence level ($p < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

gender (female vs. male), the gardener's experience, the homegarden's age, farm's size (area) and the locality. The Akaike Information Criterion (AIC) was used to select the models with the best fit and quality for the three response variables (IAP, IBP and ISP). We used statistically significant independent variables ($p < 0.05$) to propose models that help explain the level of the presence of the different indexes. We generated a

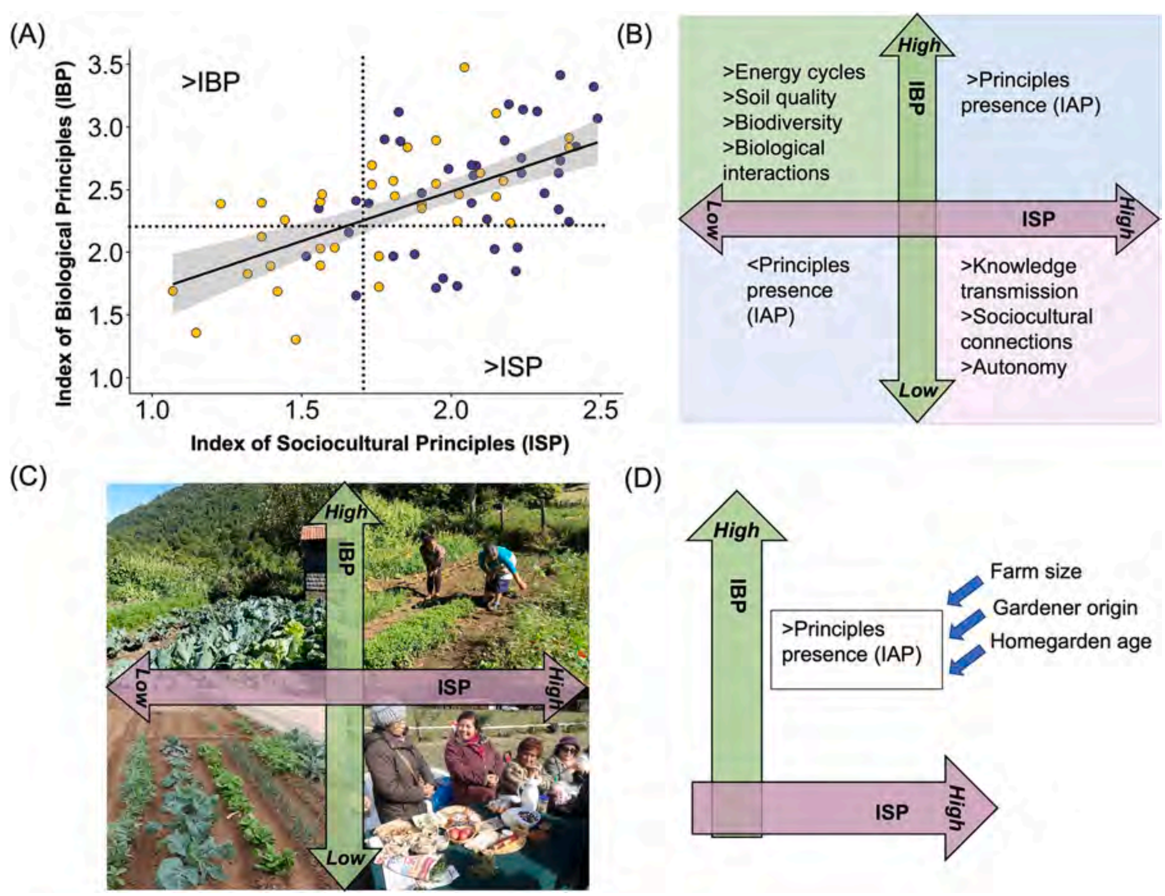

Fig. 4. (A) Estimated correlation between Index of Biological Principles (IBP) and Index of Sociocultural Principles (ISP) for 40 campesino (blue dots) and 40 migrant (yellow dots) homegardens. $r = 0.56$, $p < 00.1$. (B) Four system quadrants according to the level of principles. (C) Examples of homegardens according to the quadrant. (D) Quadrant with high IAP is correlated by three social-ecological filters. Graphs were generated using R software version 4.0.4 (R Core Team, 2021. R: A language and environmental for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.Rproject.org/). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

set of candidate models based on model weights and the precision of the estimated coefficients (Beier et al., 2001) to identify the best models. Models with ΔAIC < 2 of the best model were considered competitive models with support. For the results on the level of presence of the agroecological principles, we used the mean ± standard deviation (SD). Variance analysis was performed to determine whether there was any difference in the means of the response variables between the different groups of the independent variable (Anderson, 2001).

3. Results

3.1. Socio-demographic profiles, homegarden attributes and presence of principles

In this study in homegardens of the southern Andes, as part of larger agroforestry systems and landscapes, we found that 84% were managed by women and 16% by men. The gardeners were 52 years old (standard deviation = ±14.2) and the homegardens were 12 years old (±12.5). Campesinos were older than migrants (57 ± 12.8 vs. 48 ± 14.4 years), had more gardening experience (42 ± 19.4 vs. 16 ± 14.15 years) and had older homegardens (17 ± 15.4 vs. 7 ± 4.9 years). There were no differences between the two groups on the farm's average size (4.6 ± 5.8 vs. 4.7 ± 8.6 ha), but the data was very dispersed, with 7 ha for the 75th percentile of campesinos compared to 3.75 ha for migrants. Furthermore, campesinos managed homegardens with higher values for the index of sociocultural principles (2.28 ± 0.2) than homegardens from migrants (1.93 ± 0.4).

When analyzing the level of presence of each agroecological principles (score of 0 to 1), all seven principles were found to be present in the homegardens (Fig. 3). Most had a presence of over 0.5 (50%), with values ranging from 0.4 to 0.7 across homegardens. Out of the seven principles, those with the highest presence were biodiversity (0.72 ± 0.01), knowledge transmission (0.68 ± 0.02) and biological interactions (0.66 ± 0.01) (Fig. 3). The least present principles were soil quality (0.37 ± 0.01) and sociocultural connections (0.57 ± 0.01).

3.2. Relation between biological principles index and sociocultural principles index

Considering the homegardens of both campesinos and migrants, we found values of 2.8 (±0.6) for the Index of Biological Principles (IBP), 2.1 (±0.3) for the Index of Sociocultural Principles (ISP), and 4.9 (±0.8) for the Index of Agroecological Principles (IAP), from the 35 practices evaluated. The IBP was strongly correlated with the ISP ($r = 0.56$; $p < 0.01$; Fig. 4A, B).

3.3. Differences in practices and principles between campesinos and migrants

The practices most present among campesinos were the use of organic fertilizer and the saving of seeds (both with 100%) while, among migrants, the most present practices were the use of organic fertilizer and medicinal plants (both with 100%) (Appendices, Table A.2).

In campesino homegardens, the practices most present were those that reflect the principles of knowledge transmission (0.79 ± 0.02), biodiversity (0.75 ± 0.02) and biological interactions (0.7 ± 0.02). In the case of migrants, the most recurrent practices were those associated with biodiversity (0.68 ± 0.02), biological interactions (0.62 ± 0.02) and biomass recycling (0.60 ± 0.02) (Fig. 3). When comparing the extent to which the seven principles were present in campesino and migrant homegardens, differences were observed in biological interactions (0.70 ± 0.02 vs. 0.62 ± 0.02), knowledge transmission (0.79 ± 0.02 vs. 0.57 ± 0.02) and sociocultural connections (0.59 ± 0.01 vs. 0.54 ± 0.02). These differences in the level of presence of the principles were also apparent in the composition, structure and colors of the homegardens (Fig. 4C).

Table 3
Ranking of models for Index of Biological Principles (IBP), Index of Sociocultural Principles (ISP) and Index of Agroecological Principles (IAP) as a function of social-ecological filters. Locality was the random term in all models tested. Model structure in grey indicates the best models with equivalent support (Δ AIC ≤ 2).

Model structure	K[a]	AICc[b]	ΔAICc[c]	Wt[d]	LL[e]
a) Index of Biological Principles					
Homegarden age + Farm size	5	116.07	0	0.26	−52.63
Homegarden age + Farm size + Origin	6	117.31	1.24	0.14	−52.08
Homegarden age	4	117.54	1.47	0.13	−54.50
Homegarden age + Farm size + Gardener's experience	6	117.98	1.91	0.10	−52.41
Homegarden area + Origin	5	118.92	2.85	0.06	−54.05
Homegarden age + Origin	5	119.04	2.96	0.06	−54.11
b) Index of Sociocultural Principles					
Origin	4	46.34	0	0.55	−19.55
Origin + Homegarden age	5	48.33	2	0.20	−19.48
Origin + Gardener's experience	5	48.58	2.25	0.18	−19.53
Origin + Homegarden age + Gardener's experience	6	50.58	4.24	0.07	−19.44
Gardener's experience	4	58.42	12.09	0	−25.26
c) Index of Agroecological Principles					
Origin + Homegarden age + Farm size	6	177.54	0	0.25	−82.29
Origin + Farm size	5	177.74	0.19	0.23	−83.55
Origin + Homegarden age	5	179.01	1.47	0.12	−83.94
Origin + Homegarden age + Gardener's experience + Farm size	7	179.9	2.36	0.08	−85.65
Origin + Gardener's experience + Farm size	6	180.07	2.53	0.07	82.27

[a] Number of estimated parameters.
[b] AIC adjusted for small sizes.
[c] Difference in AIC between each model and the best model.
[d] Akaike weights indicate the level of support of a model among the candidate model set.
[e] Log likelihood.

3.4. Indexes and social-ecological filters

In the best models (Δ AIC ≤ 2) for the IBP (comprising the principles of energy cycles, soil quality, biodiversity and biological interactions), the independent variables that were the most influential social-ecological filters were the size of the farm, its age and the origin and experience of the gardener (Table 3a). However, the gardener's origin and experience were not conclusive (p-value > 0.05). The selection of the model showed that the IBP was positively correlated with the farm's size (Fig. 5a; ß = 0.014) and its age (estimated ß = 0.011; Fig. 5a).

The model with highest support for the ISP (comprising the principles of knowledge transmission, sociocultural connections and productive and/or financial autonomy) had only one social-ecological filter: the gardener's origin (Table 3b). In other words, there is an association between the gardener's origin and the ISP, which was stronger in campesino homegardens (average ± standard error = 2 ± 0.04; ß = 2.04) than in the case of migrants (1.7 ± 0.05; ß = −0.308) (Fig. 5b).

For the IAP, three were considered the best models (Table 3c). They included two to three social-ecological filters: the homegarden's age, farm's size and the gardener's origin (Fig. 4D). The results showed a positive correlation between the farm's size and the IAP (Fig. 5c; ß = 0.019). The best models also supported an association between the gardener's origin and the IAP. In campesino homegardens, this effect was larger and positive (4.5 ± 0.1; ß = 4.27) while, for migrant homegardens, it was smaller and negative (3.9 ± 0.12; ß = −0.4) (Fig. 5c). The best models also showed an association between the homegarden's

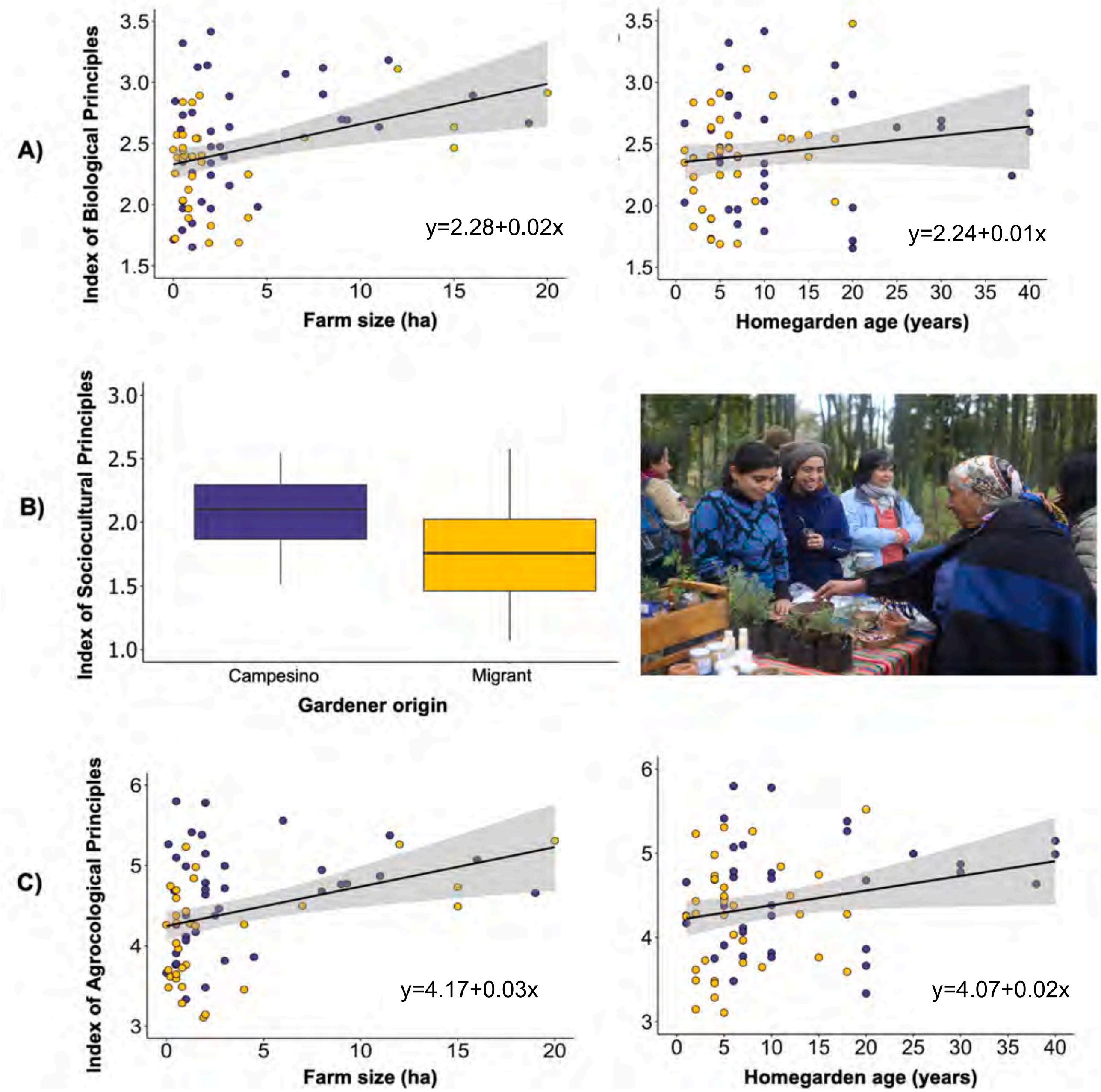

Fig. 5. Response of Index of Biological Principles (A), Index of Sociocultural Principles (B) and Index of Agroecological Principles (C) to the most influential social-ecological filters in homegardens, including farm size (ha), homegarden age (years) and gardener's origin. Graphs were generated using R software version 4.0.4 (R Core Team, 2021. R: A language and environmental for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.Rproject.org/). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

age and the IAP (Table 3c; ß = 0.01) but this filter was not conclusive (p-value > 0.05).

4. Discussion

Our study conducted in a Global Biodiversity Hotspot and an Important Agricultural Heritage System, expands previous research on homegardens as complex social-ecological systems that apply a diversity of practices, conducive to different levels of agroecological principles. Our results show a relatively high level of presence of agroecological principles within dynamic ecological, cultural and social realities in the southern Andes, indicating that both campesinos and migrants still base their management mainly on agroecological practices. This result associates with the steep relationship between biological principles and sociocultural principles, in relation to a random expectation, that may be influenced by gardener origin, farm size and homegarden age.

In our study, we found that some practices may be performing similar roles in promoting the presence of agroecological principles, regardless of the gardener's origin. For example, the practices for soil care utilized by many migrants (e.g. compost application, crop cover and mulching, Appendices, Table A.2), may help increasing the pool of practices that campesinos traditionally implement to boost soil fertility (e.g. incorporation of organic fertilizers and rotation of crops, Appendices, Table A.2 Marchant et al., 2020).

However, we should also critically examine the potentially unexpected outcomes of lifestyle migration such as gentrification processes that may change local social fabrics (Perlik, 2011). Although the integration of different sources of knowledge can potentially strengthen food sovereignty (Ibarra et al. 2019), many historical and contemporary processes associated with the arrival of 'modern practices' into traditional farming systems may negatively affect campesino livelihoods, even causing abandonment of traditional crops, with a resulting homogenization of traditional agrifood systems (Barreau et al., 2019). Thereby, it is key to foster horizontal dialogues in which campesinos and migrants can genuinely learn from each other, acknowledging the fact that campesinos (especially Mapuche indigenous) have inhabited the territory for several generations, which can in turn favor both crop diversification and food sovereignty (Meynard et al., 2016).

Based on the experience of the homegardeners, their management practices and the sociocultural relationships they have built in the territory, we identified the extent to which biological and sociocultural agroecological principles are present in a bid to understand farming systems in territories in constant change. Being a campesino (indigenous or non-indigenous) and having a relatively larger and older homegarden increase the probability that the principles of energy cycles, soil quality, biodiversity, biological interactions, knowledge transmission, sociocultural connections and productive and/or financial autonomy will be present, giving a higher IAP. This suggests that campesinos, with older homegardens inherited from their ancestors, received not only the land but also seeds, its nutrient-rich soils and knowledge about agroecological management practices. These results are in line with those of similar studies that report a relation between a gardener's cultural origin and the homegarden's composition, structure and functioning, which tend to reflect local tastes, food culture and customs (Ibarra et al., 2021; Trinh et al., 2003). There is also a positive correlation between a farm's size and the IAP. This may be related to the homegarden's position as part of a larger and complex agroforestry system and the role of the heterogeneity of the landscape and/or community in facilitating certain practices. However, it is important to bear in mind that historical processes of colonization, land fragmentation and reduction of property sizes may affect the presence of agroecological practices, making difficult to have an agroecological management in increasingly smaller properties (Barreau et al., 2019). Similarly, Pacicco et al. (2018) report that, in Italy, agrobiodiversity levels are related to the scale of the analysis. Thus, future studies could examine other social-ecological filters that can influence agroecological practices, such as the role of State extension programs, connectivity to the nearest market and percentage of the harvest that is for family consumption or sale, among others.

The IAP for campesino homegardens was higher than for those of migrants. In particular, the former had a higher level of (1) biological interactions, (2) knowledge transmission and (3) sociocultural connections. The principle of biological interactions seeks to promote synergies between the different components of the farming system and, in this way, affect ecological processes and services. Campesinos tend to promote synergies of this type more than migrants through practices such as crop rotation and the use of animal manure, insectary flowering plants and fruit trees. These agroecological practices are based on local ecological knowledge about the interaction between the soil, insects, animals, trees and other biodiversity components of the system (Marchant et al., 2019; Marchant et al. 2020). The level of presence of the principle of biological interactions may also be related to farm size (the most influential socio-ecological filter in the IBP), since several of these practices (e.g. an agroforestry system with fruit trees, biological corridors and the integration of animals) necessarily require a relatively large piece of land.

Our results also show a higher presence of the knowledge transmission principle among campesinos than migrants. This is understandable considering the tradition of oral knowledge transmission of campesinos through which, along with plant genetic material, they have passed down experiences to new generations (Barreau et al., 2016; Mellado, 2014). Mothers and grandmothers are a often an essential source of knowledge (Quilaqueo et al., 2014) and, for campesinos, children and grandchildren are subjects of teaching. This is often different with lifestyle migrants in the study area, who are generally the first generation to learn homegarden management and often have other sources of knowledge, such as practical workshops and on-line courses. Sociocultural connections also had a higher presence among campesinos than migrants, reflecting practices that strengthen community dialogue and local networks. Campesinos have lasting roots in the territory where they have established a social fabric and networks of cooperation and support. This is in line with the work of Barreau and Ibarra (2019), about the effects of campesino family farming on strengthening identity and social fabrics.

Biodiversity is the principle with the highest presence in the homegardens studied. We can understand this result because homegardens are generally a multipurpose place, with different uses (e.g. alimentary, medicinal, ornamental, identity). Each of these uses involve "an input" to the biodiversity of the homegarden. An alimentary purpose brings vegetables, fruit trees, legumes, potatoes; medicinal brings different medicinal plants; ornamental insectary brings flowers and plant pest-traps; and identity brings plants with evocative tastes, memories and personal emotions.

Crop diversity increases the stability of cropping system yields and is a reliable long-term option to address several social-ecological changes in farming systems (Beillouin et al., 2021; Tilman et al., 2006). We used generalized linear mixed-effect models to evaluate the contrasts between campesinos and migrants and, in this way, trace social-ecological changes in local farming systems. Although these models and the created indexes of agroecological principles are a simplification of reality and do not fully reflect the complexity of farming systems, they are an important tool for understanding historical and contemporary changes occurring in the southern Andes and design management options. Moreover, since the instrument is flexible, it can be tested in other social-ecological contexts, adapting the instrument's agroecological practices to the specific realities of each territory. For example, in a Mayan milpa system in Mexico (maize, beans and squash), polyculture agroecological practices and green manures are used (Gómez Betancur et al., 2018) while, in Peru, tubers are grown using rotation, local varieties and communal cultivation (Kendall and Rodríguez, 2009).

The sociocultural background of the inhabitants of the territory studied here is characterized by the migration of groups with diverse cultural and geographical origins. While the campesinos have experienced long-term processes of trial, error, selection and cultural learning, thus creating sustainable food systems (Toledo, 2017), migrants have used other sources of learning (internet, books, workshops, support networks and contact with other gardeners). There is no recipe on "how to be agroecological". Agrifood systems have changed through the interaction between the diversity of cultures and ecosystems, resulting in multiple ways of conceiving and designing agroecological systems. This interaction is constantly constructed and deconstructed as new agents of social-ecological change emerge (Cortés et al., 2019). Considering this, the different voices and myriads of homegarden communities should be open to social groups that do not have the same identity. This exchange between different groups of gardeners may be crucial to strengthen social fabrics in intercultural contexts (Bengoa, 2007) and design sustainable, resilient and diverse agrifood systems.

5. Conclusion

This study demonstrates that family farming systems in general, and homegardens in particular, are important scenarios for the implementation of agroecological practices and associated principles in the southern Andes. By building and empirically validating indexes based on three chief dimensions of agroecology (the biological, the sociocultural and the integration of both), we found that the levels of presence of agricultural principles were relatively high in homegardens of both

Table A.1
Agroecological practices and their contribution to seven agroecological principles. The x indicates the principle evaluated. Each principle refers to an agroecological principle listed in Table 1.

			Biological principles				Sociocultural principles		
N	**Agroecological practice**	**Codification**[c]	**Energy and material cycles**	**Soil quality**	**Bio diversity**	**Biological interactions**	**Knowledge transmission**	**Sociocultural connections**	**Autonomy**
1	Compost application[a]	0 = a; 1 = p		x					
2	Use of vermiculture[a]	0 = a; 1 = p	x	x		x			
3	Cover crops and/or green manures[b]	0 = a; 1 = p	x	x	x	x			
4	Cultivation of medicinal plants[b]	0 = a; 1 = p			x	x	x		x
5	Use of animal manure[a]	0 = a; 1 = p	x	x		x			
6	Production of animal manure[a]	0 = a; 1 = p	x	x		x			x
7	Mulching[b]	0 = a; 1 = p	x	x					
8	Crop rotation[a]	0 = a; 1 = p	x	x	x	x			
9	Grow an orchard (*quinta*)[b]	0 = a; 1 = p	x	x	x	x			x
10	Trees inside the homegarden[b]	0 = a; 1 = p		x	x	x			
11	Sustainable forest management[a]	0 = a; 1 = p	x	x	x	x			x
12	Production of fodder for animals[a]	0 = a; 1 = p	x	x	x	x			x
13	Integration of animals in the homegarden[a]	0 = a; 1 = p	x			x			
14	Integrate living fences[b]	0 = a; 1 = p		x	x	x			
15	Use of external/internal organic amendments[a]	0 = a; 1 = p		x					x
16	Use of insectary flowers (attract)[b]	0 = a; 1 = p			x	x			
17	Use of insectary flowers (repel)[b]	0 = a; 1 = p	x		x	x			x
18	Family contributes to homegarden work[a]	0 = a; 1 = p					x	x	x
19	Gardening with children[a]	0 = a; 1 = p					x	x	
20	Parents or grandmothers taught gardener[a]	0 = a; 1 = p					x	x	
21	Member of a cooperative or association[a]	0 = a; 1 = p						x	x
22	Belongs to an indigenous community[a]	0 = a; 1 = p					x	x	x
23	Participate in seed exchange (*Trafkintu*)[a]	0 = a; 1 = p	x		x		x	x	x
24	Community helps with homegarden[a]	0 = a; 1 = p						x	
25	Participate in extension project[a]	1 = a; 0 = p						x	x
26	Receive State support [a]	1 = a; 0 = p							x
27	Specialization in one entry[a]	1 = a; 0 = p						x	x
28	Utilize tools[a]	1 = a; 0 = p							x
29	Significant income from selling[a]	0 = a; 1 = p							x
30	Sell in local markets[a]	0 = a; 1 = p						x	x
31	Water access problem[a]	1 = a; 0 = p	x						x
32	Water efficiency[a]	0 = a; 1 = p	x						
33	Save seeds[a]	0 = a; 1 = p	x		x			x	x
34	Buy inorganic seeds[a]	1 = a; 0 = p	x						x
35	Land rights[a]	0 = a; 1 = p					x		x

[a] Declared practices.
[b] Observed practices
[c] a = absence; p = presence.

campesinos and migrants. However, we have shown that the socio-demographic profiles of gardeners and the homegarden attributes act as social-ecological filters and, therefore, can drive the presence of agroecological principles in both our study area and beyond. We consider that our indexes, adapted to local realities, should be tested in different systems as they can be useful tools for the design of public policies oriented to strengthen family farming in areas subject to the increasing pressures of social-ecological changes.

CRediT authorship contribution statement

Josefina Cortés: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Lorena Vieli:** Validation, Visualization, Supervision, Writing – review & editing. **José Tomás Ibarra:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – review & editing, Supervision, Funding acquisition, Project administration.

Table A.2
Presence of 35 agroecological practices among campesinos and migrants.

N	Management practice	Campesinos	Standard deviation	Migrants	Standard deviation
1	Compost application*	85.0	0.36	97.5	0.16
2	Use of vermiculture	50.0	0.51	62.5	0.49
3	Cover crops and/or green manures*	27.5	0.45	50.0	0.51
4	Cultivation of medicinal plants	97.5	0.16	100.0	0.00
5	Use of animal manure	100.0	0.00	100.0	0.00
6	Production of animal manure*	87.5	0.33	30.0	0.46
7	Mulching*	45.0	0.50	67.5	0.47
8	Crop rotation*	95.0	0.22	77.5	0.42
9	Grow an orchard *(quinta)*	92.5	0.27	82.5	0.38
10	Trees inside the homegarden	77.5	0.42	62.5	0.49
11	Sustainable forest management*	67.5	0.47	42.5	0.50
12	Production of fodder for animals*	55.0	0.50	10.0	0.30
13	Integration of animals in the homegarden	35.0	0.48	25.0	0.44
14	Integrate living fences	57.5	0.50	65.0	0.48
15	Use of external/internal organic amendments	45.0	0.50	60.0	0.50
16	Use of insectary flowers (attract)	80.0	0.41	92.5	0.27
17	Use of insectary flowers (repel)	70.0	0.46	75.0	0.44
18	Family contributes to homegarden work	75.0	0.44	60.0	0.50
19	Gardening with children	65.0	0.48	62.5	0.49
20	Parents or grandmothers taught gardener*	97.5	0.16	35.0	0.48
21	Member of cooperative or association	37.5	0.49	22.5	0.42
22	Belongs to an indigenous community*	42.5	0.50	2.5	0.16
23	Participate in seed exchange *(Trafkintu)*	90.0	0.30	80.0	0.41
24	Community helps with homegarden*	17.5	0.38	57.5	0.50
25	Participates in extension project*	85.0	0.36	10.0	0.30
26	Receive State support	35.0	0.48	7.5	1.62
27	Specialization in one entry*	20.0	0.41	0.0	0.00
28	Utilize tools	27.5	0.45	15.0	0.36
29	Significant income from selling*	32.5	0.47	10.0	0.30
30	Sell in local markets*	37.5	0.49	2.5	0.16
31	Water access problem	30.0	0.46	30.0	0.46
32	Water efficiency	28.2	0.46	37.5	0.49
33	Save seeds*	100.0	0.00	90.0	0.30
34	Buy inorganic seeds	57.5	0.50	40.0	0.50
35	Land rights*	97.5	0.16	82.5	0.38

*Significant differences with a 95% confidence level ($p < 0.05$).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendices

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