Traditional knowledge and use of plants as agricultural insecticides from a gender perspective in three rural communities of the Ecuadorian Andes

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Research

Abstract

Background. In Ecuador, plants have traditionally been used to control crop pests as an alternative to chemical pesticides. In this study, we evaluate the state of knowledge surrounding these plants among farmers in three rural communities of the Ecuadorian Andean region and analyze, in turn, whether this knowledge is conditioned by gender.

Methods. Semi-structured surveys were designed with demographic information, as well as information related to the use of plants to control pests in crops. A total of 240 surveys were administered to farmers in the three selected sectors (120 men and 120 women), followed by on-site visits to contrast the information collected. To determine the importance of the species, the use value (UV) of each species was analyzed, and the Fidelity Level (FL) and informant consensus factor (ICF) indices were established to quantitatively analyze the consensus among the responses collected. The number of species used was also analyzed, as well as the possible differences in the way in which these species were prepared and handled, depending on the genus.

Results. Thirty-four percent of respondents use plant-based insecticides as the main source of pest control. A total of 21 species were identified for this purpose. The species with the highest use values were *Ruta graveolens* L. (**ruda**) (UV=0.62), *Capsicum annuum* L. (**ají)** (UV=0.58), and *Allium sativum* L. (**ajo)** (UV=0.35). The majority of respondents (60 %) use them to treat the pest caused by *Bemisia tabaci* Gennadius (**white fly**). The main form of preparation consists of the maceration of 2-3 species, which is applied preventively every 15-30 days. From the surveys, there are slight differences in usage between men and women. There is a higher percentage (55 vs. 40 %) of usage in women, while the average number of species and total number of species are both similar (between 2 and 3 species used in combination and 18 vs. 17 species, respectively). The main differences are of a qualitative nature and refer to the different use values of some species compared to others.

Conclusions. The results of this work show a worrying erosion of knowledge concerning the use of plant species as insecticides for agriculture. Only 34 % of the respondents use them and only two species have a UV > 0.5 (*R.graveolens* and *C. annuum*). Although there are slight differences in usage between men and women, most of these differences refer to the preference of some species over others and, therefore, knowledge of these species does not seem to be significantly influenced by gender.

Keywords: Traditional Knowledge, Insecticide plants, Pest Control, Gender lens, Andean Region, Ecuador

Background

The adaptation of local populations and their resilience to the various social, economic, and environmental changes they suffer cannot be understood without considering their ability to interact with the natural environment, which is the product of knowledge transmitted over many generations. This interrelationship between habits, beliefs, and natural resource management, which Folke (2004), Berkes *et al.* (2000), and other authors define as traditional ecological knowledge (hereinafter TEK), has been investigated from different disciplines, including ethnobotany, whose findings have allowed us to better understand how plants contribute to the health of communities, the maintenance of cultural heritage, and the conservation of people's natural heritage.

Ecuador, due to its biodiversity and cultural richness, with 14 recognized Indigenous nationalities to date (INEC 2022), has been the subject of numerous ethnobotanical studies from colonial times to the present (Paniagua-Zambrana and Bussmann 2020, de la Torre *et al.* 2008, Moraes R *et al.* 2006). These studies show, on the one hand, that there are about 5172 plants with some type of benefit for the communities (de la Torre and Macía 2008) and, on the other hand, that most of the studies have focused on the medicinal, food, construction, or ritual use of these species.

One of the least-studied functions, which is nevertheless key to the communities' sustainability, refers to the use of plants in pest control. The use of plant species as pesticides, also known as botanical insecticides, is common among communities worldwide (Anjarwalla *et al.* 2016). Its practice dates back in some regions to more than 2,000 years ago (Isman 2019). With the advent of the Green Revolution in the middle of the last century, the use of botanical insecticides was gradually replaced by chemically synthesized products. Agrochemicals were initially welcomed for increasing crop productivity and yield, but, as pointed out by Campos *et al.* (2019), among many other authors, the indiscriminate use of these products led to a multitude of environmental, toxicity, and resistance problems that have led to a decrease in their current performance.

Therefore, at present, there is a resurgence of interest in environmentally friendly products (Amoabeng *et al.* 2019, Campos *et al.* 2019, Isman 2019), given the current context of global change and the fact that the use of plant species as pesticides for agriculture can contribute to the fulfillment of the Sustainable Development Goals 1, 2, and 12 (United Nations 2015). These goals refer to ensuring food security, reducing poverty, and promoting responsible consumption and production by minimizing the risks derived from pesticide application, decreasing production costs, and favoring the conservation of biodiversity within the framework of family farming activities.

This growing interest has resulted in a multitude of publications that refer to knowing the active components of these plants and their potential use in crop protection (Akbar *et al.* 2022, Hikal *et al.* 2017, Isman and Grieneisen 2014); however, one aspect that is less studied is the current state of knowledge surrounding these species and their role in the communities' sustainability.

In the Ecuadorian Andean region, there are some classic studies that deal exclusively with this aspect. Evans (1989) showed the traditional use of *Ricinus communis* L. for the control of different coleopteran pests in communities in the northern region of the Ecuadorian Andes. Later, Ayats and Zabala (2000) reported the use of 20 species with pesticide potential in a community in Imbabura. Kvis and Alarcón (2008), through a bibliographic review, described the use of 35 species (75 records) as potential insecticides, where the families Asteraceae, Solanaceae, and Lamiaceae were the most representative. They highlighted the role of *Ambrosia arborescens* Mill (**marco**) as the most cited species. In a recent study conducted by our research group in a Kichwa community in the Andean region, 13 species with this function were identified, and it was also possible to verify how farmers perceived that the gradual replacement of plants as regulators of pest control processes in favor of chemical synthesis products contributed to a loss of economic crop yield within family farming settings (Hernández Maqueda *et al.* 2022).

Furthermore, to understand the state of knowledge surrounding the use of plant species within the various communities, one aspect that must be considered is the different roles that men and women play within the community (Tng *et al.* 2021). In many Ecuadorian communities, there is a division of labor between men and women, with women having greater knowledge about the benefits that plants can bring to the community, as has been pointed out by various authors (Hernández Maqueda *et al.* 2021a, Caballero-Serrano *et al.* 2019, Díaz-Reviriego *et al.* 2016).

Therefore, the main objective of this study was to investigate the state of knowledge and use of plants as natural insecticides in three communities in the province of Cotopaxi, in the Ecuadorian Andes, and, as a complementary objective, to determine whether there is differential knowledge between men and women in these communities.

Material and Methods

This work was carried out in three rural communities (Belisario Quevedo, San Buenaventura, and Tanicuchi) in the province of Cotopaxi, Ecuador. They are located in the inter-Andean region (0°58'0"S, 78°34'0"W; 0°54'0"S, 78°36'0"W; 0°46'60"S, 78°37'60"W, respectively), as shown in Fig. 1.

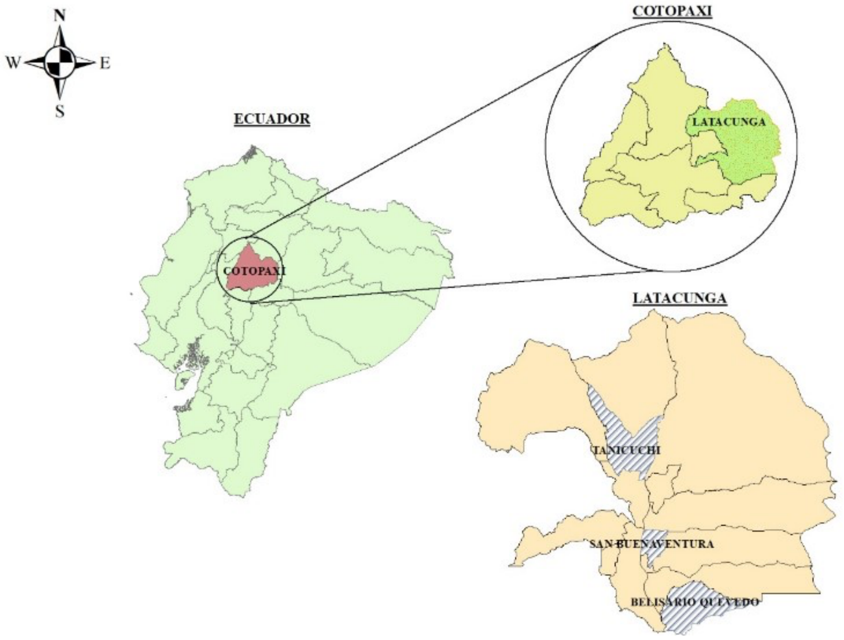

Figure 1. Map of the study area showing the three selected parishes

These localities belong administratively to the Latacunga canton. Their altitudes range from 2,680 m to 5,897 m. Precipitation fluctuates between 500 and 1000 mm per year, with rainfall peaks in March-April and October-November. The temperature in the study localities ranges from 10° to 14°C. The presence of winds, and eventually frosts, contributes to the harshness of the climate. Soils are of the molisol type, characterized by deep, fertile soils with abundant organic matter, which favors the development of agriculture and cattle raising in the region. There is a high degree of deforestation, with a majority presence of forest masses of introduced species, mainly eucalyptus (*Eucalyptus* spp.) and pine (*Pinus* spp.). The three communities have a total population of 28750 inhabitants (Belisario Quevedo: 6359, San Buenaventura: 9560, and Tanicuchi: 12831). There are Mestizos (86.40% of the total), Andean Kichwa (8.55%), white people (2.75%), Afro-Ecuadorians (1.50%), and the rest belong to other minority nationalities, mainly Montubios (0.65%) (INEC 2022). The main economic activity is derived from subsistence agriculture and livestock farming, whose products are mainly sold in local markets. The main crops are potatoes (*Solanum tuberosum* L.), cereals such as barley (*Hordeum vulgare* L.), and different varieties of corn (*Zea mays* L.), as well as fava beans (*Vicia faba* L.), peas (*Pisum sativum* L.), and common beans (*Phaseolus vulgaris* L.). It is also worth noting the increasing presence of fruit crops, as well as the increase in export products, such as roses (*Rosa* spp.) and broccoli (*Brassica oleraceae* var. *italica* Plenk), are changing the productive landscape of the region, increasing the presence of large agricultural areas managed by companies and displacing family farming.

The selection of these three communities within the region is due to their strong farmer organizations, which group together family production units that manage their crops in a traditional way, putting into practice different types of management considered as ancestral in the Ecuadorian context.

Data collection

To collect information about the state of traditional knowledge of plants in the selected communities, a semi-structured survey was designed with information about the knowledge and use of plants to control pests and diseases in crops, as well as the parts used, the mode of preparation, dosage, frequency of application, main crops, and pests to which they are applied. In addition, information was collected on the age, educational level, and gender of the respondents. The interviews were applied *in situ* between the months of September 2020 and March 2021, after signing the prior consent report (PIC) form and safeguarding COVID-19 safety protocols.

To calculate the population size, the following formula was applied for finite samples: [1] $n = \frac{z\times p \times q \times N}{e\text{^}2(N-1)+z\times p \times q}$

where z = Confidence level, p = Probability of Success, q = Probability of Error, N = population size, and e= Error Level.
In this study, N represents the group of people registered in agricultural and farmers' associations in the three communities (3583 people). The sample size established for this study was 240 people (with a confidence level of 95% and margin of error of 6%).

Demographic information of the respondents

Since one of the objectives of the study was to identify possible differences between men and women with respect to knowledge of plants as agricultural insecticides, the number of men and women surveyed was the same (120). In addition, Table 1 shows the number of respondents according to age and educational level. The different age ranges selected are represented in a similar percentage, with the > 60 age range being the least numerous group, with 40 people, representing 18% of the total, and the 41-50 age range being the most numerous, with 62 people, representing 26% of the surveyed population. Regarding the educational level, 60% of the respondents have primary school level or have not finished high school. Only 7% of those surveyed have a university degree.

Table 1. Demographics of respondents (n=240) according to gender, age, and education level

Variable	**Category**	**n**	**%**
Total		**240**	**100**
Gender	Male	**120**	**50**
	Female	**120**	**50**
Age range	<30	**52**	**22**
	31-40	**42**	**17**
	41-50	**62**	**26**
	51-60	**40**	**17**
	>60	**44**	**18**
Educational level	Illiteracy	**24**	**10**
	Primary level	**141**	**59**
	Secondary level	**58**	**24**
	University level	**17**	**7**

Ethical approval for data collection

In order to preserve and protect traditional knowledge and its applications, this study was designed within the framework of international regulations defined for this purpose as the Convention on Biological Biodiversity (CBD 1992) and the Nagoya Protocol on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising from their Utilization (SCBD 2011). It is also based on Ecuadorian national legislation (Código Orgánico de la Economía Social de los Conocimientos 2016). Specifically, in this study, to obtain the collection on the use and knowledge of plant species, farmers were randomly selected from among the different agricultural and smallholder organizations present in the three parishes. Since this study includes a gender approach, it was considered that the participation of men and women was balanced in each study community. All the people who participated in the study received a detailed explanation about the objectives of the work and signed the respective PIC for the development of the work.

Subsequently, the corresponding permit was obtained from the Ecuadorian Environment Ministry, authorization number MAAE-ARSFC-2020-0740, for the collection of plant specimens.

Specimen collection and deposit

With the permission of the farmers, a reference specimen of each species cited in each community was collected, which totaled 51 specimens. The identification, conservation, and deposit of the specimens were carried out in the Herbarium of Applied Botany at the Technical University of Cotopaxi (UTCEC), with collection numbers UTCEC_DPila_[1:51].

Quantitative analysis of the information reported

First, the respondents' state of knowledge surrounding botanical insecticides was determined.
Subsequently, to contrast the information about species use, the following ethnobotanical indices were applied.

Use Value (UV)

To calculate the importance of each species, the use value of each taxon was calculated (Phillips and Gentry 1993) according to the following formula:

[2]: UV= Ui/N

where Ui represents the number of use reports for a given taxon divided by the total number of respondents (N).

Fidelity Level (FL)

This index (Friedman *et al.* 1986) was used to identify the specificity of use of a given ethnospecies on a given agricultural pest

[3]: FL = Ip/ Iu × 100

Here, "Ip" represents the number of respondents who reported specific use of a particular plant, and "Iu" represents the total number of respondents who mentioned the plant for any use.

Informant Agreement Ratio (IAR) (Heinrich et al. 1998)

Although this indicator has traditionally been used to detect categories of medicinal plants, in this work we adapted it for agricultural use, understanding each category as different pests. Consequently, in this study:

[4]: IAR = Nur-Nt / Nur-1

Here, "Nur" represents the number of times a given species is cited to treat a given pest, and "Nt" represents the total number of plants used to treat that specific pest.

Finally, differences in the number of species (total and average) used were analyzed, as well as differences in the mode of preparation and application according to genus.

Statistical analysis

Statistical analyses were performed with the free software R, version 4.2.3 (R Core Team 2022). The package *readxl* v. 1.3.2 was used to read Excel spreadsheets, and the package *ggplot2* version 3.4.1. was used to make figures.

The number of known species was analyzed according to gender, age range, and educational level.

To check the distribution of the data for this variable, a normality test was first performed. By means of this test (S-W=0.8885, p<0.000001), it was observed that the data do not fit a normal distribution. Consequently, to know the differences for these variables according to gender, a nonparametric test for independent samples based on U-Mann-Whitney was performed. For the analysis of the number of species known as a function of age and different educational levels, an ANOVA for nonparametric samples (Kruskal-Wallis) was performed.

Finally, a network analysis was carried out using the *igraph* v. 1.4.1. and *tydiverse* v.2.0.0 packages to illustrate the combinations of species used to treat a given pest.

Results

Characterization of knowledge on plant species used as insecticides

The first aspect that should be highlighted is the use of plants as insecticides in agriculture is common knowledge among those surveyed. Seventy-nine percent of them know or have used plants as biological insecticides on some occasion. However, if we look at Fig. 2, we can see that only 93 of them (39% of the total) use them on a daily basis. When analyzing the state of knowledge according to the three demographic variables analyzed, we can see that the use of plants is slightly higher in women than in men: 55% vs. 45% (Fig. 2, top), the groups that use them most are those with primary education (56%) followed by secondary education (Fig. 2, middle), and the age range that uses plants as insecticides most often is 41- to 50-year-olds (Fig. 2, bottom).

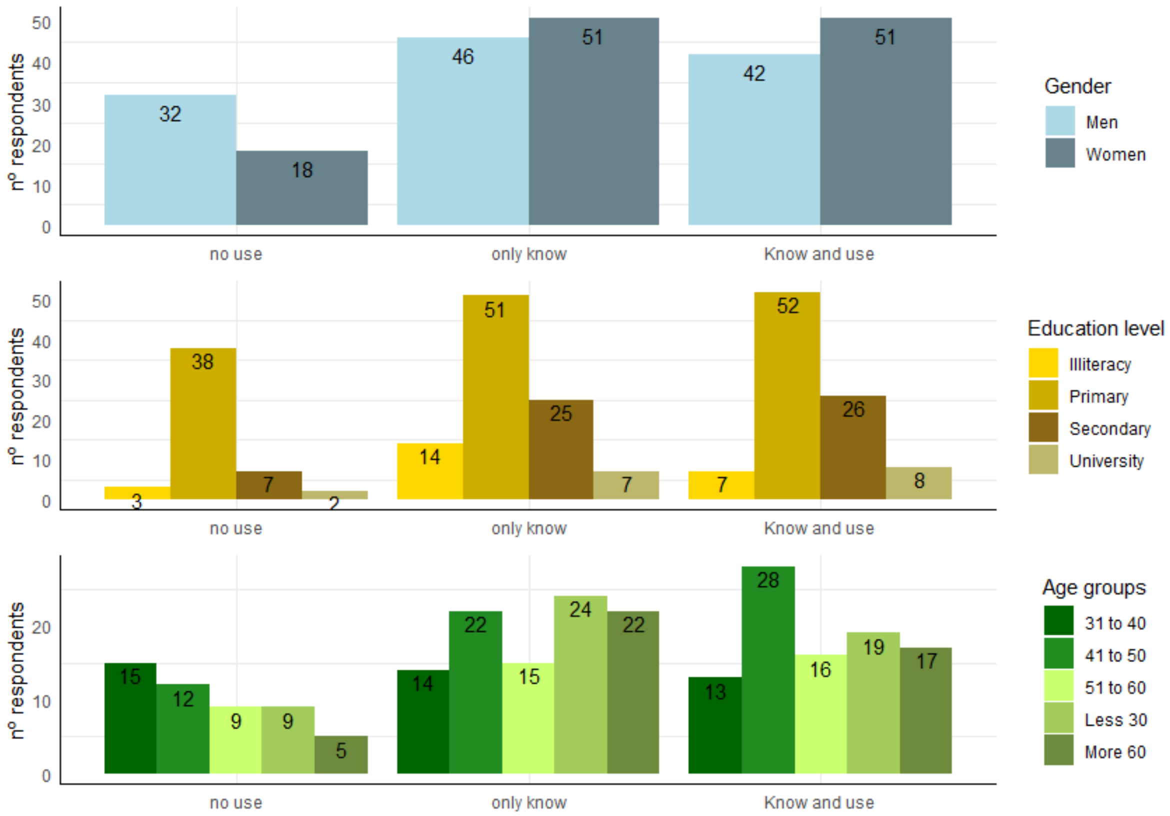

Figure 2. Knowledge of plant species as insecticides in agriculture as a function of gender, educational level, and age

Diversity of species used as agricultural insecticides

Table 2 shows the different plant species used as agricultural insecticides in the three parishes analyzed. A total of twenty-one species corresponding to twelve botanical families were identified. The most numerous families were Asteraceae (five species), Solanaceae (four species), Rutaceae, and Amaryllidaceae (two species each), and the rest of the families with one species. Eight of the species are native and the remaining thirteen are introduced. The species with the highest use value (UV) were *Ruta graveolens* L. (**ruda)** with a UV of 0.62, followed by *Capsicum annuum* L. (**ají),** (UV=0.58). Five species have a use value of between 0.10 and 0.50: *Allium sativum* L. **ajo** (UV=0.35), *Ambrosia arborescens* Mill. (**marco**) (UV=0.26), *Urtica dioica* L. (**chagra ortiga**) (UV=0.25), *Eucalyptus globulus* Labill. (**eucalipto**) (UV=0.13), and *Tanacetum parthenium* Smith. (**santa maria**) (UV=0.10). The remaining fourteen species, which account for 66% of the species identified as insecticides, have a use value of less than 0.10.

Table 2. Diversity of plants used as agricultural insecticides. N=native, I=introduced, UV=Use Value

Scientific name	Vernacular name	Voucher	Origin	UV	Parts used
Amaryllidaceae					
Allium cepa L.	Cebolla	UTCEC_DPila5	I	0.03	Bulbs
Allium sativum L.	Ajo	UTCEC_DPila4	I	0.35	Bulbs
Apiaceae					
Apium graveolens L.	Apio	Utcec_DPila39	I	0.01	Leaves
Asteraceae					
Ambrosia arborescens Mill.	Marco	Utcec_DPila10	N	0.26	Leaves, stems
Artemisia absinthium L.	Ajenjo	UTCEC_DPila1	N	0.06	Leaves, stems
Baccharis latifolia (Ruiz & Pav.) Pers.	Chilca	UTCEC_DPila6	N	0.02	Leaves, stems
Matricaria chamomilla L.	Camomila	UTCEC_DPila9	I	0.04	Leaves, flowers
Tanacetum parthenium Smith	Santa María	UTCEC_DPila33	N	0.10	Leaves, flowers
Fabaceae					
Medicago sativa L.	Alfalfa	UTCEC_DPila21	I	0.01	Leaves
Lamiaceae					
Salvia rosmarinus Schleid.	Romero	UTCEC_DPila13	I	0.04	Leaves, flowers
Myrtaceae					
Eucalyptus globulus Labill.	Eucalipto	UTCEC_DPila24	I	0.13	Leaves, fruits
Plantaginaceae					
Plantago major L.	Llantén	UTCEC_DPila44	I	0.01	Leaves
Rutaceae					
Citrus x aurantiifolia (Christm.) Swingle	Limón	UTCEC_DPila27	I	0.01	Fruits
Ruta graveolens L.	Ruda	UTCEC_DPila32	I	0.62	Leaves,stems, flowers
Scrophulariaceae					
Buddleja globosa Hope	Matico	UTCEC_DPila29	N	0.02	Leaves
Solanaceae					
Brugmansia sp.	Floripondio	UTCEC_DPila42	N	0.05	Leaves, flowers
Capsicum annum L.	Ají	UTCEC_DPila36	I	0.58	Fruits
Capsicum pubescens Ruiz & Pav.	Ají rocoto	UTCEC_DPila37	I	0.04	Fruits
Solanum cf. *americanum* Mill.	Hierba mora	UTCEC_DPila43	N	0.02	Leaves, stems
Urticaceae					
Urtica dioica L.	Chagra ortiga	UTCEC_DPila30	I	0.25	Leaves
Viburnaceae					
Sambucus nigra L.	Sáuco	UTCEC_DPila34	N	0.04	Leaves, stems

In total, men used 17 species for this purpose and women 18. On average, between two and three species were used per farm, regardless of the gender surveyed. The main differences with respect to gender refer to the different use values that men and women give to some species compared to others. Thus, *C. annuum* is the species with the highest use value in men (UV=0.69) and *R. graveolens* in women (UV=0.59).

Fig. 3 shows the deviation of the use value of the responses of women compared to men. If we look at the differences in the use value according to gender, we see that there are some notable differences. Women use *A. arborescens,* (**marco**) *C. pubescens* (**ají rocoto**), and *T. parthenium* to a greater extent than men (0.12, 0.08, and 0.05 units of deviation, respectively). It can also be seen in the graph how there is a lower use of *A. sativum* **ajo**, *C. annuum,* **ají** and *R.graveolens* **ruda** by women as compared to men (-0.26, -0.2, and -0.08, respectively).

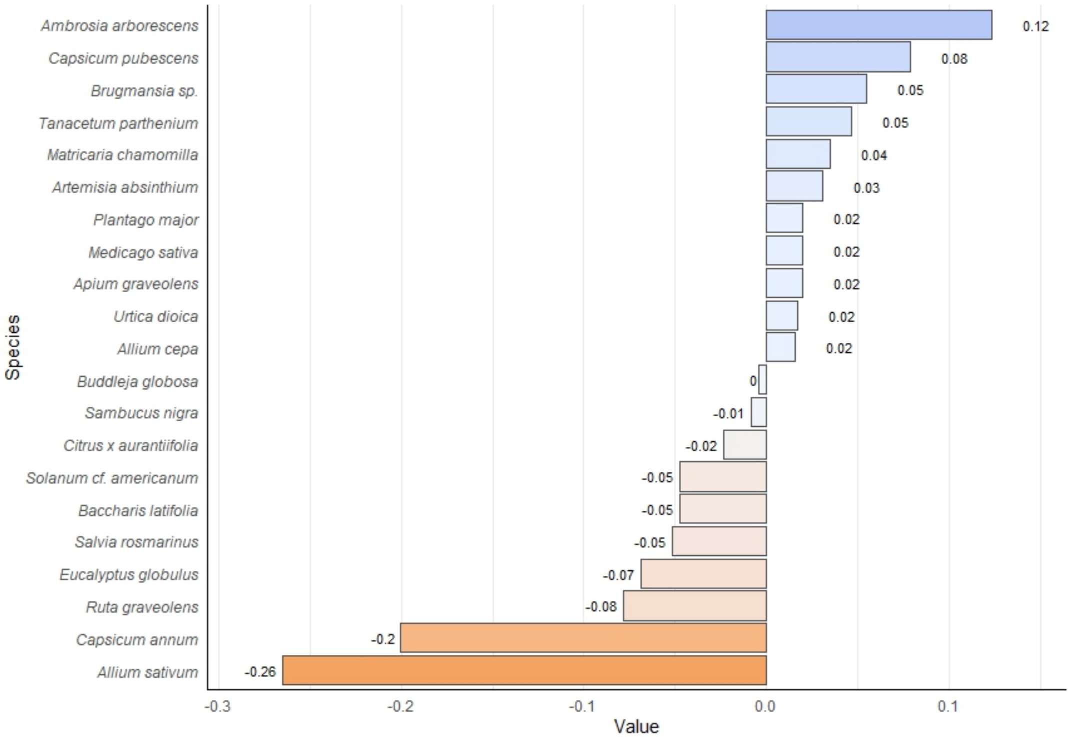

Figure 3. Variation in the use value of the different plant species used by women with respect to men

Diversity of treated pests

Through the surveys and the subsequent on-site visit, it was possible to identify the use of plants for the treatment of four main pests: 60% of the respondents use plants to combat pests caused by *Bemisia tabaci* Gennadius (**white fly**), which affects a large proportion of the crops produced in the area, 17% use them to treat problems caused by *Myzus persicae* Sulz. (**aphid**), 12% for *Frankliniella occidentalis* Pergande (**western flower thrip**), and 11% to treat different species of *Spodoptera* spp. (**nemathods**). Only 2% of the interviewees use the plants in addition to insecticide to treat fungal diseases such as *Phytopthora infestans* (Mont.) de Bary, (**lancha**).

As can be seen in Table 3, there is consensus among the respondents in the use of *C. annuum*, *R. graveolens*, and *A. sativum* to treat *B. tabaci* Gennadius (FL of 0.60, 0.50, and 0.50 and IAR of 0.62, 0.66, and 0.34, respectively). For the rest of the pests, different combinations of species were used with the FL not exceeding 0.20 and IAR 0.26 (Table 3).

Table 3. FL and IAR of the 5 species with the highest use values in the three communities used to treat the main pest identified. N/A=Not available

Species	**White fly**		**Aphids**		**Western flower thrips**		**Nemathods**	
	FL	IAR	FL	IAR	FL	IAR	FL	IAR
Ruta graveolens L.	0.50	0.66	0.20	0.26	0.10	0.07	0.10	0.07
Capsicum annuum L.	0.60	0.62	0.20	0.13	0.10	N/A	0.10	N/A
Allium sativum L.	0.50	0.34	0.10	N/A	0.10	N/A	0.20	N/A
Ambrosia arborescens Mill.	0.60	0.05	0.10	N/A	0.20	N/A	0.10	N/A
Urtica dioica L.	0.60	0.14	0.20	N/A	0.10	N/A	0.10	N/A

Mode of preparation and application

The main ways of preparing plant-based insecticides are by: a) maceration (68% of respondents), b) extraction (16% of respondents), and c) infusion (16%). For maceration, the leaves and stems are introduced (between 0.5 and 1 kg per plant), the fruits and bulbs (in the case of "**ají**" and "**ajo**" or "**cebolla**") are liquefied and placed in an opaque 20-liter container with water and at room temperature. The container is placed in a cool place out of direct sunlight. It is moved every 2-3 days. The maceration process usually lasts between 7 days and 15 days. On the other hand, the extraction is mainly performed when the part of the plant to be extracted is hard (bulb or more or less dry fruit), as with *A. sativum* or *C. annuum.* In this case, 10 chili peppers and 10 whole garlic heads are usually used, which are liquefied and then diluted in 5 or 10 liters of water. Finally, for the infusion, the parts of the plant (between 0.5 kg and 1 kg of plant material) are poured into a container with hot water (20 liters) and boiled. The farmers then remove it from the heat, let it stand for 5 minutes, strain it, and the solution is applied to the crops.

Forty percent apply the mixture directly without dilution, 28% make a 1:2 mixture-water dilution, i.e., 500 ml of mixture in 1 liter of water, and the rest make a larger dilution before applying it to a given crop (Fig. 4B). Ninety percent use insecticides preventively, regardless of pest appearance, with a frequency of 30 days (51%), 15 days (34%), and 7 days (10%). The remaining 10% apply them only when the pest appears, at which point they are applied daily until the pest disappears (Fig. 4C).

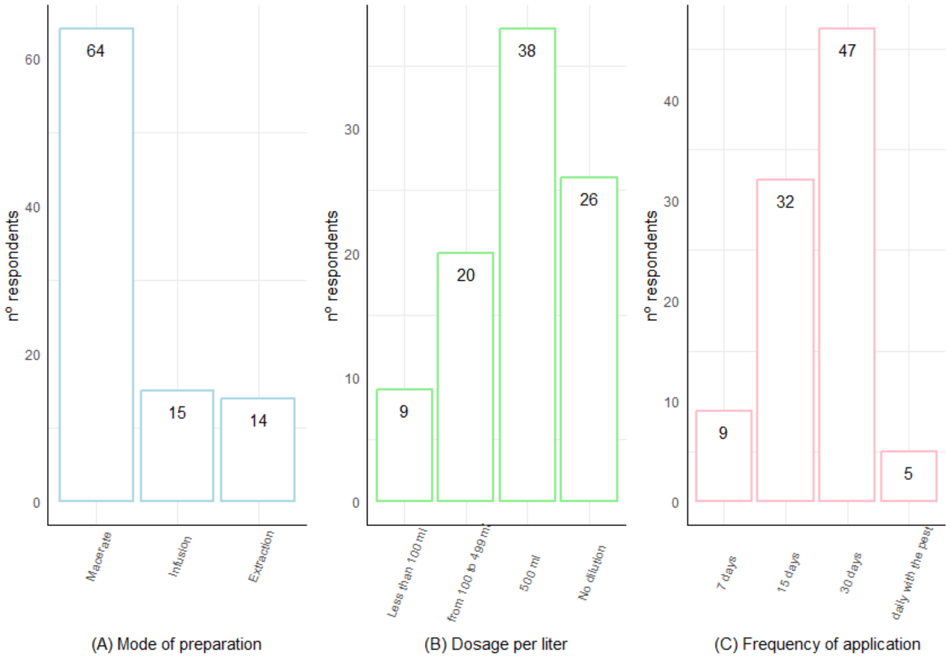

Figure 4. Mode of preparation, dosage, and frequency of application of the insecticide

In all cases, the plants are collected from the plots where they are grown, forming, in most instances, living barriers together with other species that act as borders or provide shade. Slightly more than 53% use two or three species mixed together to prepare the insecticide, 29% use a mixture of more than three species, and slightly less than 18% use a single species, which in most cases is *C. annuum* as an insecticide.

Fig. 5 shows a representation of the different combinations used to treat the main pest defined by the respondents *(B. tabaci)*. Each vertex represents the different species, and the thickness of each edge represents the number of times a certain combination is mentioned. It can be seen how there are certain differences in the use of plants between men and women. In the case of men, combinations using *C. annuum*, *R.graveolens*, and *A. sativum* as the main species predominate. On the other hand, the combinations are more varied in the case of women, showing the importance of other species such as *U. dioica*, *E. globulus*, *A. arborescens*, and *T. parthenium*.

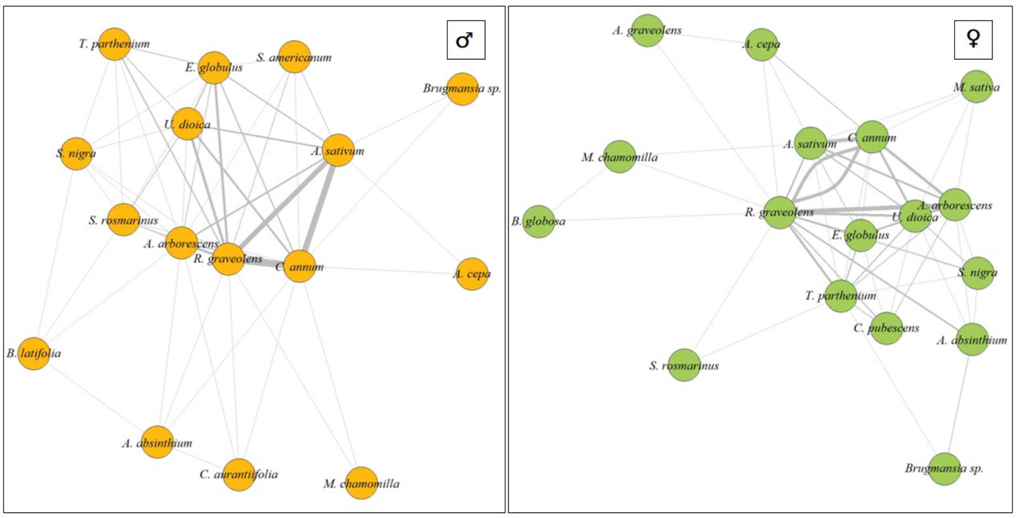

Figure 5. Combination of species used to treat *B. tabaci* according to gender. Each vertex represents one species (see table 2)

Discussion

Characterization of knowledge on plant species used as insecticides

Overall, a first approximation to the results could lead us to the erroneous interpretation that a high state of knowledge is maintained, judging by the number of species cited (21 in total), which is consistent with the number of species cited for this purpose in previous studies (Hernández Maqueda *et al*. 2022, Kvis and Alarcón 2008 and Ayats and Zabala 2000), and because 190 farmers (79% of respondents) know some type of botanical insecticide. However, a closer look at the data shows that only 39% of the respondents use them on a daily basis. Furthermore, there are only two species with a UV > 0.50 (*R. graveolens* and *C. annuum*), and 14 (66% of the species identified as insecticides) have a use value of less than 0.10, which shows a worrying erosion of knowledge surrounding the use of this type of species in the communities. This could indicate a loss-of-knowledge pattern according to Tang and Gavin (2016). In the case of the communities studied, this could be due to two main factors, namely market demands that impose strict control over the products used as phytosanitary products, thereby favoring the use of agrochemicals over natural products, and the influence of industrial agriculture models present in the region, mainly regarding the production of roses, which undervalue this type of knowledge (Gortaire 2016).

Another noteworthy aspect is the greater knowledge and use of introduced species than native species for pest control. Only eight native species are used for this purpose, and of these, only *A. arborescens* has a remarkable UV (UV = 0.26). This result is not surprising and is consistent with Hart et al. 2017, who analyzed more than 40,000 ethnobotanical records in Ecuador and showed that there is greater use of introduced species than native species in this region due to their greater availability, versatility, and diversification.

Diversity of species used as agricultural insecticides

The species with the highest use values in the community (*C. annuum*, *R. graveolens A. sativum*, *A. arborescens,* and *U.dioica*) are highly valued species in the Ecuadorian Andean region and are known for their multiple uses (Paniagua-Zambrana and Bussmann 2020, de la Torre *et al.* 2008, Moraes R *et al.* 2006). All of them, according to the aforementioned authors, are medicinal, but they also fulfill other functions that provide different services and benefits to the communities.

If we consider the insecticidal properties, perhaps the best-known species beyond the scope of this research is *C. annuum* mainly known for its culinary use as a food condiment (Ulloa 2006). Its potential as an insecticide, known among farmers in the Andean region, is due to the presence of capsaicinoids that have antifungal (Moreno *et al.* 2016) and larvicidal effects (Claros Cuadrado *et al.* 2019) and that, according to Cabrera Verdezoto *et al.* (2016), has an insecticidal potential similar to others of commercial origin.

With respect to "**ruda**", its main use in the region is social, specifically to attract good fortune (Armijos *et al.* 2014). Its insecticidal potential is due to the presence of different phenolic compounds that have been shown to be effective against coleopterans (Jeon *et al.* 2015) and various dipterans (Cárdenas *et al.* 2010).

The insecticidal properties of garlic, in turn, are due to the presence of dimethyl trisulfide,and diallyl disulfate, amongst others compounds (Plata-Rueda *et al.* 2017), whose use at different doses has shown efficacy against different species of coleoptera (Mukesh Kumar 2017, Plata-Rueda *et al.* 2017).

Finally, of all of them, the most versatile species is *A. arborescens*, which is used in the region as a medicine, to attract good luck, to control diseases in crops and livestock, and sometimes also as a food supplement for livestock (Paniagua-Zambrana and Bussmann 2020). This versatility was also observed by Hernández Maqueda *et al.* (2021b, 2022) in a study conducted in a Kichwa community in the Ecuadorian highlands, where this species reached a UV of 1.49. Its insecticidal potential is known in the Ecuadorian region, so in recent years different trials have been conducted to evaluate its potential against the larvae of *Aedes aegypti* L., the main vector of diseases such as dengue or chikungunya (Morejón et al. 2018).

Diversity of treated pests

It is crucial to mention that, in this study, there is little specificity and consensus for the treatment of a given pest in a specific crop. The greatest consensus was obtained for the use of "**ají**" and "**ruda**" in combination with different species for the treatment of whitefly. This observation is consistent with that reported by Hernández Maqueda *et al.* (2021b), Brechelt (2004), Ayats and Zabala (2000), who show that different species are used combined to control different types of pests.

In future research projects, it would be advisable to focus on the active principles of the plants analyzed and on the influence of different combinations of species on the effectiveness of combatting a given pest in order to favor the synergy between scientific knowledge and ancestral knowledge and to allow the use of botanical insecticides to become an increasingly efficient alternative in family agriculture.

Gender differences regarding the mode of preparation and application

Finally, in this work, slight differences in use are observed between the management of men and women, and most of these differences are of a qualitative nature, such as the preference of using some species over others, or the preparation of different combinations to treat a particular pest, so that, in this work, traditional knowledge does not seem to be so strongly conditioned by gender contrary to the findings of Tng et al. (2021) and Camou-Guerrero *et al.* (2008). Nonetheless, it must be recognized that the study has focused on a group of plants with a very specific function that could be conditioning this interpretation due to the limited number of plants used (21 in total and 2-3 on average per farmer), so to understand in depth whether the genus influences the knowledge of plant species in these communities, it is advisable to perform future studies to include more categories of use, similar to the studies conducted by various authors (e.g., Tng *et al.* 2021, Caballero-Serrano *et al.* 2019, Díaz-Reviriego *et al.* 2016, Arango, 2004).

Conclusions

This paper shows the state of knowledge and use of plants as insecticides among farmers in three rural communities in the province of Cotopaxi in the Ecuadorian Andes. The results of this work show a worrying erosion of knowledge regarding this specific use, limited to a few species. Only 34% of respondents use them and only two species have a UV > 0.5 (*R. graveolens* and *C. annuum*). Although use is somewhat higher in women than in men, the fact is that there are no main differences in the use of botanical insecticides between men and women, except in differential management and certain differences in the preference of some species over others. In order to reverse the erosion of this type of knowledge and guarantee its preservation, it would future studies are necessary in order to focus on the causes that favor the loss of use of these species and to study in-depth the advantage of their use in favoring the adaptability and resilience of family agriculture in the context of global change.

Declarations

Ethics approval and consent to participate: The data were collected with respect to confidentiality, anonymity, and consent by the participants.
Consent for publication: Not applicable.
Availability of data and materials: The data were not deposited in public repositories. Data are available upon request from the author for correspondence. The Ecuadorian Ministry of Environment's Permit Report, Consent Report, and Applied Surveys are available through the following public repository: **http://repositorio.utc.edu.ec/handle/27000/7608**
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Authors' contributions: Daysi Pila contributed to the study design, ethnobotany surveys conduction, and collection of specimens, and Rafael Hernández Maqueda to the conception and supervizing, and methodology design. Both authors contributed to the data analysis and interpretation. The first draft of the manuscript was written by RHM and DP and reviewed by RHM. Both authors approved the final manuscript.

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