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Abstract: The five independent countries of Central Asia, namely Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, contain one of the richest areas in the world for the specific and intraspecific diversity of temperate fruit and nut tree species. Research was carried out via the collaboration of national research and education institutes with local community-based agencies and farmer communities. Raw data (2014 observations) for almond, apple, apricot, cherry plum, currant, grapevine, pear, pomegranate, and walnut were collected at the household (HH) level across the five countries: Uzbekistan, Kazakhstan, Tajikistan, Turkmenistan, and Kyrgyzstan. A set of models was used, including household variety richness as the dependent variable, to understand the influence of socio-ecological variables on the amount and distribution of crop varietal diversity in the farmers' production systems. Four variables were included as explanatory variables of variety richness (fixed factors): ecoregion, ethno-linguistic group, management, and abiotic stress. The results show clear evidence that abiotic stress determines a higher richness of intra-specific diversity in the form of local varieties grown by farmers living in climatically unfavorable areas. The results for the studied ecoregions follow the same trend, with ecoregions with harsher conditions displaying a higher positive correlation with diversity. Mild environments such as the Central Asian riparian woodlands show an unexpectedly lower diversity than other harsher ecoregions. Ethno-linguistic groups also have an effect on the level of varietal diversity used, related to both historic nomadic practices and a culture of harvesting wild fruit and nuts in mountainous areas. The home garden management system hosts a higher diversity compared to larger production systems such as orchards. In Central Asia, encouraging the cultivation of local varieties of fruit and nut trees provides a key productive and resilient livelihood strategy for farmers living under the harsh environmental conditions of the region while providing a unique opportunity to conserve a genetic heritage of global importance.

Keywords: intraspecific diversity; resilience; environmental stress; horticultural crops; risk management; climate adaptation; ethno-linguistic diversity; Central Asia

1. Introduction

The five independent countries of Central Asia, namely Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, contain one of the richest areas in the world for specific and intraspecific diversity of temperate fruit and nut tree species [1]. Important horticultural crops commonly used in temperate farmland worldwide, including Apple (*Malus domestica*), apricot (*Prunus armeniaca*), pear (*Pyrus communis*), cherry plum (*Prunus cerasifera*), currant (*Ribes negrum*), pomegranate (*Punica granatum*), grape (*Vitis vinifera*), almond (*Amygdalus communis*), and walnut (*Juglans regia*), have their primary centers of diversity in Central Asia. These perennial crops, domesticated in the region, spread to temperate areas globally, following commercial trade routes [2–15]. Diverse, extreme natural and climatic conditions, coupled with human influence over the past three to four millennia, marked by the selection and development of varieties of these perennial fruit and nut trees, have provided productivity and resilience to the production systems of smallholder farmers in the region [9,16–18]. This dense reservoir of varieties adapted to specific environments of Central Asia is of high value for today's farmers and future breeding and development [18–21].

Today, Central Asia continues to host a remarkable diversity of many of these species [9,18,22,23]. This genetic base of Central Asia's cultivated fruit and nut trees continues to be expanded today by the constant interaction of cultivated varieties with wild materials collected by farmers, such as rootstock and graft wood adapted to local harsh abiotic conditions and biotic stress [9]. The genetic pool is maintained and shaped by traditional knowledge transmitted from one generation to the other in the farming population [18]. Local grafting practices in orchards and home gardens are passed down through generations to incorporate locally adapted varieties into the production systems of these harsh environments [24].

The development of arboriculture in Central Asia represents an investment for longer-term returns compared to those gained from annual crops, which has, in turn, shaped both the agricultural landscapes and local livelihood strategies toward durable benefits and resilience [25–27]. Horticulture in Central Asia has been increasingly studied in the past decade with the aim of improving the conservation of fruit and nut trees in the area [28]. Despite the collectivization of agriculture during the Soviet era, the production of fruit and nut trees remained important at the family level in Central Asian countries. Perennial crop production has increased since independence, supporting the need for households to be resilient during the economic transition [10] as new independent countries in Central Asia moved out of mainly cooperative farms into individual farming households. Market demand for local fruit and nut crop varieties has increased during the past ten years, combined with farmers' interest in local fruit crop varieties, especially apple, pear, and grape [18].

From 2006 to 2013, a coordinated global partnership of researchers working with farming communities in five Central Asia countries measured the amount and distribution of fruit and nut tree genetic diversity in the form of traditional, improved (improved varieties from regional materials) and introduced (exotic materials from outside the region) varieties in farmers' fields of nine fruit and nut tree species (Figure 1). Via this partnership, countries worked together, using globally applicable diversity indices, developed for annual crops [29], to compare across farmer households and socioecological zones the amount and distribution of perennial fruit and nut tree varietal diversity. This paper (i) synthesizes the total body of fruit and nut tree diversity data gathered on-farm in the study; (ii) demonstrates that considerable fruit and nut tree genetic diversity continues to be maintained in family farms; (iii) examines socio-ecological variables, abiotic stress, management space, ecoregion, and ethno-linguistic group, to better understand how these factors affect and explain the observed varietal richness in fruit and nut trees of Central Asia; and (iv) provides an analytical framework for determining the role of on-farm fruit and nut tree genetic diversity in the production and resilience of family farms. The readaptation of fruit and nut tree cultivation once out of the Soviet era and the long lifespan of these perennial crops make the dataset collected extremely valuable for analysis for policy recommendations in the region today.

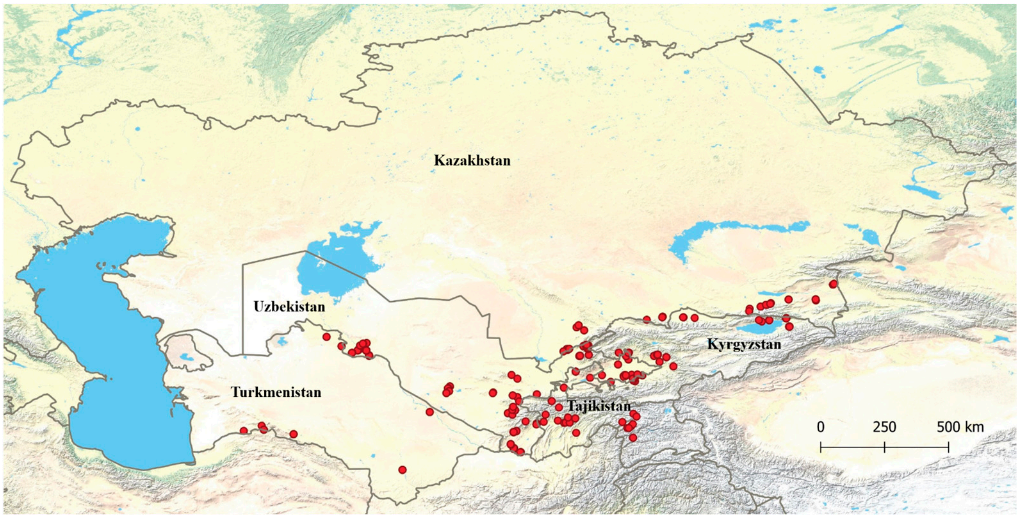

Figure 1. Sampled households across country sites (red dots).

2. Materials and Methods

2.1. Study Sites

Research was carried out in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan via the collaboration of national research and education institutes with local community-based agencies and farmer communities. Economic development ranged from less-developed (lower middle income) economies in Kyrgyzstan, Tajikistan, and Uzbekistan, to the more-developed (upper middle income) economies such as Kazakhstan and Turkmenistan, which are oil-based (World Bank Country and Lending Groups webpage (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519, accessed on 11 September 2023). Seventeen social economic zones were selected to encompass environmental, cultural, technological, and economic differences (see Tables S1 and S2 in Supplementary Materials for details). Figure 1 presents the locations of the sampled households across the five studied countries.

The survey spanned socio-economic zones, covering 11 ecoregions as defined by Olson et al. [30]: the Alai-Western Tian Shan steppe; the Badghyz and Karabil semi-desert; the Central Asian northern desert; the Central Asian riparian woodlands; the Central Asian southern desert; the Gissaro-Alai open woodlands; the Kopet Dag semi-desert; the Kopet Dag woodlands and forest steppe; the Pamir alpine desert and tundra; the Tian Shan foothill arid steppe; and the Tian Shan montane conifer forests. Site elevation ranged from 100 m a.s.l. to 1800 m a.s.l. Precipitation in the sites ranges from 80 mm to 1000 mm, falling predominantly from October to May. In the south, temperatures reach over 45 °C in the summer months and can drop to as low as −25 °C in the coldest months throughout Central Asia in the plains. Eight major ethno-linguistic groups, Kazakh, Kyrgyz, Russian, Tajik, Turkish, Turkmen, Uygur, and Uzbek, were located in the communities surveyed. The average size of home gardens was 0.026 hectares. The average orchard size per crop was approximately one hectare but ranged from 0.002 ha in Turkmenistan for cherry plums to 95 ha for grapes in Kazakhstan.

2.2. Sampling on Farms and in Communities

The farms were sampled to represent a broad picture of the fruit and nut tree varietal diversity in the five Central Asian countries. Raw data (2014 observations) for almond, apple, apricot, cherry plum, currant, grapevine, pear, pomegranate, and walnut were collected at the household (HH) level across the five countries: Uzbekistan, Kazakhstan, Tajikistan, Turkmenistan, and Kyrgyzstan. At each HH, data were collected on all varieties and genotypes grown by the farmer for the targeted fruit and nut trees of the study, using a standardized participatory diagnostic survey adapted from Jarvis and Campilan [31] and the Diversity Assessment Tool for Agrobiodiversity and Resilience (DATAR) [32]. Information was collected on variety names, number of trees, ethno-linguistic group of the farmer (inferred from the language used for the interview), ecoregion, and management type (orchard or home garden). Fruit and nut tree varieties are characterized by Central Asians into three groups: traditional, modern, and introduced. Traditional varieties (synonym for landrace) are defined as farmer recognized crop varieties possessing a certain genetic integrity that evolved in cultivation over long periods, adapted to a specific local environment or purpose. Modern varieties are defined as varieties improved, registered, and released in the national research breeding systems in Central Asia Institutes. Introduced varieties are defined as certified varieties developed outside Central Asia. The nomenclature, identification, and consistency of variety names follow the methods described in Jarvis et al. (2008) [29]. Subsequently, data were aggregated for the analysis in order to obtain variety richness for each fruit tree species at the HH level, also considering the type of management arrangement.

2.3. Data Analysis

A set of generalized linear mixed models (GLMM) was used, including household variety richness as the dependent variable. The GLMM was used to evaluate the effect of the socio-ecological variables on the distribution of fruit and nut tree diversity in Central Asia for data collected from 388 households, with ecoregion, ethno-linguistic group, management, and abiotic stress as fixed effects. Data were analyzed at a regional level, pooling together data from different fruit tree crops and countries. This type of approach presents some difficulties due to the nature of the data: (1) data are unevenly distributed in each country (i.e., different sampling efforts and different interests in specific fruit tree crops); and (2) different fruit tree species are characterized by their own variety richness due to biological reason and selection effort by farmers. Richness data (count data) do not follow a normal distribution. In order to control all these factors, we used a GLMM that can handle non-normal data (richness) and control for bias due to the structure of the data [33].

Ethno-linguistic groups were defined on the basis of the language used for the interview of the farmers; management represents the arrangement of fruit trees in small groups for domestic or local use (*home garden*) or in larger lands and devoted mainly to market (*orchard*). Ecoregions included semi-desert, northern desert, riparian woodlands, southern desert, open woodlands, woodlands and forest steppe, alpine desert and tundra, montane foothill arid steppe, and montane conifer forests across Central Asia. Ecoregions were obtained from the map of terrestrial ecoregions provided by Olson et al. [30]. Ethno-linguistic groups were based on the main language identified by the household: Kyrgyz, Russian, Tajik, Turkish, Turkmen, Uygur, and Uzbek. Finally, climatic stress represents a combined variable derived from the worldclim database (https://worldclim.org/, accessed on 11 September 2023), from which we extracted BIO1 (annual mean temperature); BIO5 (maximum temperature of the warmest month); BIO6 (minimum temperature of the coldest month); BIO12 (annual precipitation); B016 (precipitation in the wettest quarter); and B017 (precipitation of driest quarter), as they are known to influence fruit and nut tree productivity [34]. Given that these variables are known to be correlated with each other and in order to avoid an inflation of variables in the models, we performed a Principal Component Analysis (PCA) of the five variables and took the first PC score (representing 75% of the total variance) as a proxy for abiotic stress.

A full GLMM was obtained, including the four fixed effects and two random effects: Country and Crop. Successively, we compared the full model with all the possible reduced models (with a combination of 3 or fewer variables) and a null model. The best-fitting model was chosen based on the Akaike Information Criterion corrected for finite sample size (AICc).

All the analyses were conducted using the R statistical environment [35]. The GLMM was performed using the package lme4 [36]. Comparisons of AICc scores between full and reduced models were carried out using the package MuMIn [37].

3. Results

3.1. Overall Diversity Estimates

Intra-specific varietal diversity for each studied fruit or nut tree at the household level, median value, and confidence intervals are presented in Figure 2. The richness of intra-specific diversity at the household level is high and variable. All the studied fruit and nut trees have an average variety richness at a household level above 2.2; Apple, Apricot, Cherry plum, Grapevine, and Pear are even above 3.7, with the highest average richness at the household level for Apricot at 4.8. Four of these crop trees show a very wide range of variety richness at the household level, ranging from 1 to 62 for Apple, 1 to 24 for Apricot, 1 to 58 for Grapevine, and 1 to 27 for Pear. The median is at 2 for Almond, Apple, Currant, Grapevine, Pear, and Pomegranate; at 3 and 4, respectively, for Apricot and Cherry plum; and 1.5 for Walnut. Detailed results of varietal diversity at the household level are available in Table S3 in the Supplementary Materials. They are also presented in Figure 2 with box plots summarizing these results.

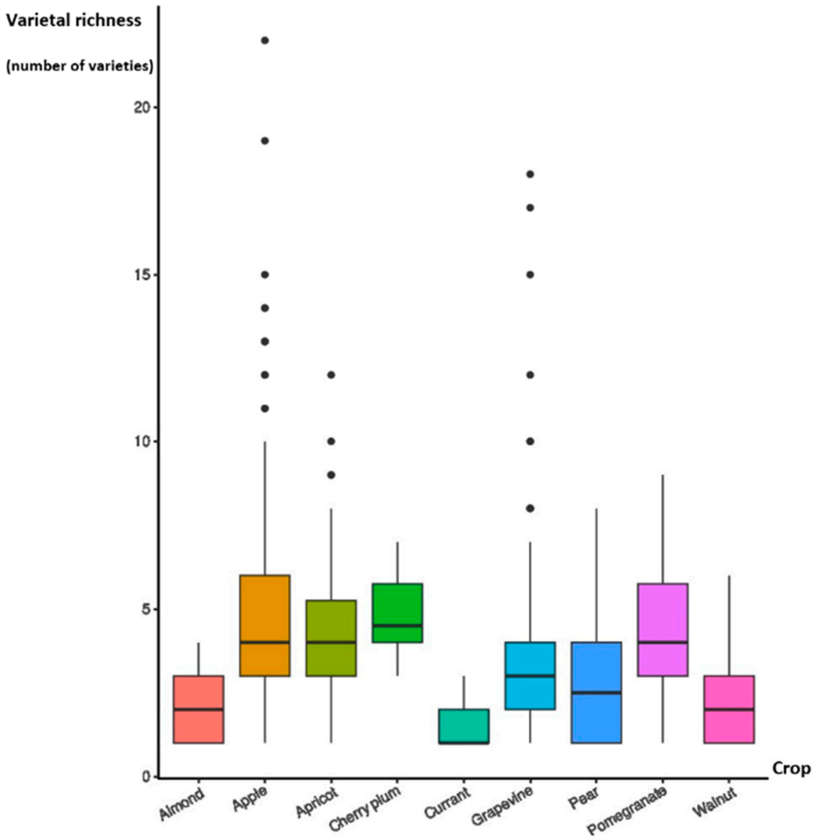

Figure 2. Intra-specific varietal richness at household level by crop (crop names on the x-axis and number of varieties on the y-axis). Bold line = median value; box = 50% of the confidence interval; whiskers = 95% of the confidence interval.

Across the five Central Asian countries, the variety richness shows very high values for apple, 188; Apricot, 79; and Grapevine, 100. These results are summarized in Table 1. The table also presents the percentages of variety types: traditional, modern, and introduced. In Table S4 of the Supplementary Materials, the full list of variety names (in Russian) by crop and their type (traditional, modern, or introduced) is also made available.

Table 1. Variety richness and percentages by type per crop at project level.

Crop	Total Number of Varieties Per Crop	% Traditional Varieties (Landraces)	% Modern Varieties Bred in Central Asia Institutes	% Introduced Improved Varieties from Outside Central Asia
Almond	11	91%	9%	0%
Apple	188	72%	6%	22%
Apricot	79	89%	1%	10%
Cherry plum	11	36%	0%	64%
Currant	7	86%	14%	0%
Grapevine	100	72%	1%	27%
Pear	47	74%	4%	21%
Pomegranate	29	86%	0%	14%
Walnut	24	83%	0%	17%
Total number/mean %	**496**	**76%**	**3%**	**20%**

3.2. Social Ecological Predictors

According to the Akaike Information Criterion corrected for finite sample size (AICc), we found that the full model is the best fitting model to explain the fruit tree diversity in Central Asia with an AIC delta of 8.06 with the next best fitting model (model that excludes ethno-linguistic groups). The model selection table is available in Table S5 in Supplementary Materials. This allowed us to robustly reject reduced models in favor of a multifactorial full model.

We then estimated the effects and their significance for the full model. Coefficient estimates, standard error, and significance are calculated for the full model with reference effects categories where management is set to the home garden, ecoregion to Alai-Western Tian Shan steppe, and Kazakh for the ethno-linguistic group. The results are presented in Table 2.

According to the estimated values for fixed factors (Table 2, Figure 3), we found that diversity increases significantly with the increase in abiotic stress; the trend is clear, and confidence intervals (CI) are narrow around the coefficient estimate. Figure 3A shows this trend clearly. Among management practices, home gardens harbor a significantly higher diversity with respect to orchards. The coefficient estimate for the management factor, despite a wide CI, shows that varieties under orchard management have clearly less varietal diversity compared to home gardens; Figure 3B gives a good visualization of the differences between the two management types. Among the ecoregions, as represented in Figure 3C, we found large fluctuations in the estimated diversity in many cases, such as the Central Asian northern desert (C), Pamir alpine desert and tundra (I), Tian Shan foothill arid steppe (J), and the Tian Shan montane conifer forests (K), which showed higher estimated values of richness whereas Badghyz and Karabil semi-desert (B), Central Asian riparian woodlands (D), Central Asian southern desert (E), and Kopet Dag semi-desert (G) showed a low diversity. Among the different ethno-linguistic groups (Figure 3D), we found significant differences, especially in the Kyrgyz, Russian, Turkmen, and Uzbek groups, which are related to a higher tree diversity. However, it is difficult to evaluate the effect of this variable due to the general wide confidence interval. Graphs in Figure 3 provide a good visualization of correlations and confidence intervals.

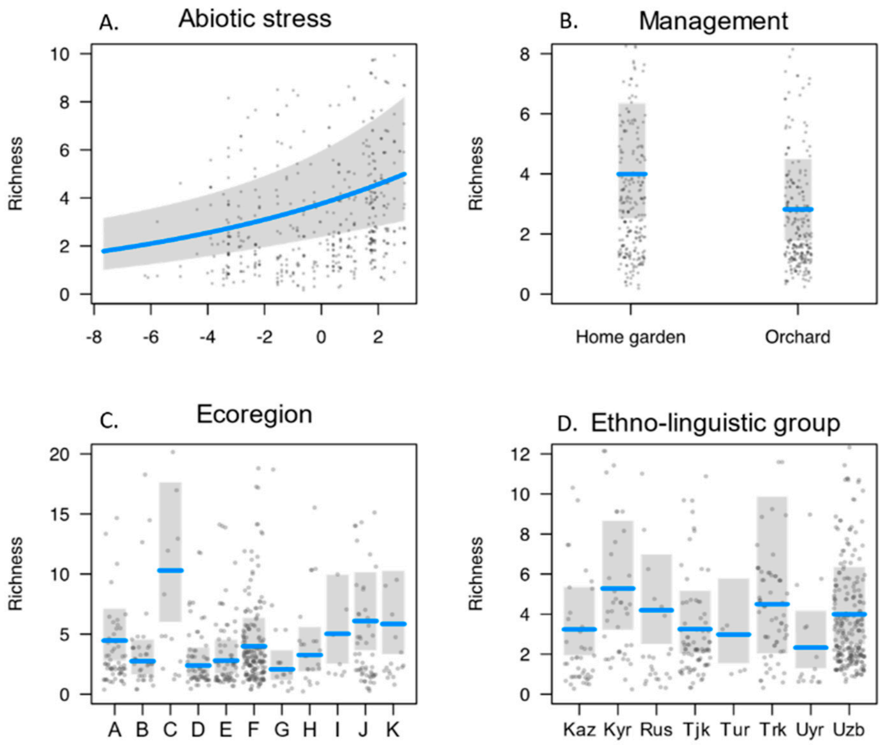

Figure 3. Relationships among variety richness and the four socio-ecological variables estimated by the full GLMM. Plots contain a confidence band, prediction line, and partial residuals (points). Ecoregion names were abbreviated as follows: Alai-Western Tian Shan steppe (A); Badghyz and Karabil semi-desert (B), Central Asian northern desert (C), Central Asian riparian woodlands (D), Central Asian southern desert (E), Gissaro-Alai open woodlands (F), Kopet Dag semi-desert (G), Kopet Dag woodlands and forest steppe (H), Pamir alpine desert and tundra (I), Tian Shan foothill arid steppe (J), and Tian Shan montane conifer forests (K). Ethno-linguistic groups were abbreviated as follows: Kazakh (Kaz), Kyrgyz (Kyr), Russian (Rus), Tajik (Tjk), Turkish (Tur), Turkmen (Trk), Uygur (Uyr), and Uzbek (Uzb).

Table 2. Estimated values for fixed factors. For each fixed, effects coefficient (coef.) estimate, standard (std.) error, z value, and significance (p) are reported. For multilevel variables (management, ecoregion, and ethno-linguistic group), the significance is relative to the first level (in alphabetical order) of the belonging variable group. For the random effects crop and country, the model estimated a variance and standard deviation of 0.2075 ± 0.4556 and 0.0865 ± 0.2941, respectively.

	Coef. Estimate	**Std. Error**	**z Value**	**p (>|z|)**
(Intercept)	1.211071	0.263782	4.591	$\mathbf{4.41 \times 10^{-6}}$
Management: Orchard	−0.346055	0.061785	−5.601	$\mathbf{2.13 \times 10^{-8}}$
Ecoregion: Badghyz and Karabil semi-desert	−0.484916	0.138486	−3.502	**0.000463**
Ecoregion: Central Asian northern desert	0.798726	0.146242	5.462	$\mathbf{4.72 \times 10^{-8}}$
Ecoregion: Central Asian riparian woodlands	−0.624811	0.133364	−4.685	$\mathbf{2.80 \times 10^{-6}}$
Ecoregion: Central Asian southern desert	−0.454274	0.112785	−4.028	$\mathbf{5.63 \times 10^{-5}}$
Ecoregion: Gissaro-Alai open woodlands	−0.155917	0.096973	−1.608	0.107868
Ecoregion: Kopet Dag semi-desert	−0.729989	0.193984	−3.763	**0.000168**
Ecoregion: Kopet Dag woodlands and forest steppe	−0.341358	0.178067	−1.917	**0.055235**
Ecoregion: Pamir alpine desert and tundra	0.159150	0.223831	0.711	0.477066
Ecoregion: Tian Shan foothill arid steppe	0.272411	0.130293	1.351	**0.036550**

Table 2. *Cont.*

	Coef. Estimate	Std. Error	z Value	p (>∣z∣)
Ecoregion: Tian Shan montane conifer forests	0.234397	0.173525	1.526	0.176760
Abiotic stress	0.082108	0.023349	3.517	**0.000437**
Ethno-linguistic group: Kyrgyz	0.439634	0.161478	2.723	**0.006478**
Ethno-linguistic group: Russian	0.261656	0.113879	2.298	**0.021580**
Ethno-linguistic group: Tajik	−0.009328	0.182743	−0.051	0.959290
Ethno-linguistic group: Turkish	−0.077775	0.235427	−0.330	0.741131
Ethno-linguistic group: Turkmen	0.349178	0.459837	0.759	0.447642
Ethno-linguistic group: Uygur	−0.331758	0.169417	−1.958	**0.050203**
Ethno-linguistic group: Uzbek	0.192472	0.157862	1.219	0.222754

4. Discussion

The aim of this research was to understand what socio-ecological variables can explain the observed varietal richness in fruit trees of Central Asia. Our analysis provides an overall picture of the main drivers of fruit tree diversity in agroecosystems of Central Asia. As expected, diversity is the product of multifactorial drivers and an interplay between environmental, abiotic, and cultural factors.

The variety richness shows impressively high results for apple, grapevine, and apricot. Traditional varieties represent over 70% of all varieties of all crops except cherry plum, showing these traditional varieties are key to agricultural production and cultural choices and are still predominantly used by farmers rather than modern or introduced varieties.

According to the estimated values and graphic representations obtained with the model (Table 1 and Figure 3), we found that all four variables tested are good predictors of fruit tree diversity in Central Asia. Our results show not only that different environmental conditions found in different ecoregions can determine different levels of varietal diversity but, unexpectedly, that more stressful conditions in an agroecosystem can trigger the planting and management of a larger number of varieties per crop than in more benign environments. We found that more extreme temperatures and low precipitation conditions are linked to higher levels of intra-specific (varietal) diversity (Figure 3A). Results for the studied ecoregions follow the same trend, with ecoregions having harsher conditions displaying a higher positive correlation with diversity, examples being the Central Asian northern desert (C), Pamir alpine desert, and tundra (I), Tian Shan foothill arid steppe (J), and Tian Shan montane conifer forests (K).

The more extreme environments in Central Asia have created conditions for higher levels of managed fruit and nut tree diversity compared to more benign environments. Numerous studies have shown that farmers living in extreme environments use higher levels of intra-specific diversity both to adapt to niche environments [38] and as a risk management strategy [39,40] to meet their production needs under changing stressful conditions [41]. Our analysis clearly shows an increase in fruit and nut tree intra-specific diversity with an increase in abiotic stress (high and low temperature and low rainfall). Most temperate fruit trees are obligatory outcrossers, requiring pollination from a compatible donor tree of a different variety before they can set fruit. Levels of pollinators are also affected by climatic conditions [42–44]. The more extreme environments in Central Asia contain a greater risk of unpredictable late frosts during flowering. Frosts just after pollination can also damage the first stages of fruit formation [45]. Farmers may use varietal diversity as a risk management strategy for both main varieties and pollinator donor trees in regions of increased unpredictability of frost onset and the length of the frost period. This strategy has also recently been recommended for apples in the Appalachian Mountains for changing frost patterns in the eastern United States [46].

Many of the ecoregions of the studied sites are subject to a dry climate. Although some have been labeled "deserts" under international classifications, the terminology can be misleading. These dry areas also contain numerous oases along their main rivers where fruit and nut trees thrive well. Ecoregions are correlated with climates. Temperatures and rainfalls vary according to the latitude and altitude. There is a wide range of ecoregions in this study; they nonetheless display some common features, such as the large fluctuation of temperatures between night and day and by seasons with a very cold winter and hot summer, and the occurrence of the limited precipitations mainly during the winter season. Overall, the results show more crop and varietal diversity in mountain areas. These results may be explained by the fact that these mountain areas host a patchwork of small econiches with various microclimates, which require the use of a diversity of adapted crops and varieties. Perennial fruit and nut tree crops display great potential for the mitigation and adaptation to climate change. Trees regulate water stress and excess on farms and are key to enhanced soil health [26,47,48], particularly important in mountain areas.

Different levels of soil salinity are also found across the ecoregions studied. Soil salinity is not correlated with ecoregions but with geographical characteristics, as is the case of saline soils in the irrigated areas of the valleys where groundwater tables are close to the surface. Farmers, faced with more or less salinity in their fields and orchards, experiment with different varieties with tolerance traits to soil salinity [49,50]. More stressful climate and soil conditions also affect levels of resistance for perennial crop species to pests and diseases. Farmers use varietal diversity to constantly adapt to evolving pests and diseases, looking for tolerance and resistance traits but also by using mixtures of different varieties within a field or orchard as part of their risk-management strategy [51–53]. Several studies have demonstrated that apple varieties and their wild relatives display various tolerance and resistance traits to diseases [54–58]. The use of varietal mixture can also play such a role [59]. By limiting the spread of epidemics, apple varietal diversity participates in disease regulation. Demestihas and colleagues (2017) [60] demonstrated the high potential for fruit trees in orchards to provide multiple ecosystem services, including pest and disease regulation and pollination, while Montanaro et al. (2017) [61] point to similar results for peach, apricot, olive groves, and vineyards in the Mediterranean area.

Among the different ethno-linguistic groups studied, we found significant differences; Kyrgyz, Russian, Turkmen, and Uzbek groups are related to a higher crop tree diversity, while Tajik and Kazakhs had significantly less diversity at the household level. These differences can be related to several cultural differences. An earlier econometric analysis in Central Asia revealed a linkage between Uzbek participation in community groups and the levels of fruit and nut tree diversity managed by households [62]. In contrast, Kazakhs are historically nomadic people and have only recently started to carry out crop farming [63], which could possibly explain the low presence of varietal diversity in this ethno-linguistic group. Tajiik people commonly live in mountainous areas that host a rich wild nut and fruit tree diversity; rather than planting a wide set of varieties for each species, they have the conditions and a culture to collect a large part of their fruits and nuts from the wild [18,64]. Farmers in countries of Central Asia where populations of wild relatives of perennial crops can rely on genetic materials extracted from wild populations present in potential surrounding natural environments. These natural environments, when they are present, provide natural laboratories for farmers to select from. It is often the case in mountainous areas, where farmers select genotypes that display stronger tolerance and resistance to the biotic and abiotic local conditions. Farmers establish their own trials and selection. They are continuing the domestication process, bringing wild materials into their cultivated environments [3,16,65].

Home gardens in the study sites harbor significantly higher varietal diversity with respect to orchards. This result is consistent with studies of home gardens globally [66]. Home gardens support the rural population's livelihood, improve food security, nutrition, and income, and provide an efficient risk management option against economic and environmental fluctuations [67]. Their contribution to overcoming the economic crisis when transitioning from state to more private-led agriculture in Central Asia has also been documented [68]. These characteristics support the use of home gardens for sustainable agriculture, respect for the environment, supporting food security, and stimulating economic growth [67]. Important diversity, including crop intraspecific diversity in the form of varieties still commonly found in home gardens that are not present to that extent in larger fields [9,29,65,67,69]. Home gardens can also be a crucial management strategy to diversify household incomes and dietary diversity in the agricultural systems of former soviet republics of Central Asia. These gardens, of small size, about one hectare on average, have been spaces where farmers could exert their own choice even during the era of collective farming [9]. They usually grow vegetables, fruits, and nuts for their own consumption and for the provision of extra income to the household. Although home gardens primarily sustain household consumption, farmers are favoring plant varieties that are easily saleable on the market to be able to liquidate their surplus production [9]. In addition, home gardens are also places where farmers experiment with new materials from the wild and test management practices for perennial crops, including fruit and nut species [16,22]. Home gardens in Central Asia are also important hotspots of fruit tree varietal diversity because they maintain rare and differentiated varieties that can provide genetic material for future agronomic practices while at the same time meeting changing market demands. Traditional knowledge, built using farmers' experience passed from one generation to the other, is favored in home gardens and embeds the importance of crop diversity and varietal diversity.

Not only do Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan share a common wealth of genetic reserves of cultivated fruit and nut species, but they also share similar traditional farming systems and the same recent historical, economic and political legacy. The five countries have similar legislative frameworks regarding land reforms and cropping patterns, with implications for national and regional governments to provide future support to the use of traditional fruit and nut tree varieties in the farmers' production systems [22]. The dramatic changes since the breakup of the Soviet Union in 1991 have greatly influenced individual farmers' freedom and capacity to cultivate different types of crops and varieties, as seen from the results of our survey. The work presented here provides a scientific basis for policy development to include the use of fruit and nut tree varietal diversity in national development planning actions.

5. Conclusions

In Central Asia, encouraging the cultivation of local varieties of fruit and nut trees provides a key productive and resilient livelihood strategy for farmers living under the harsh environmental conditions of the region while at the same time providing a unique opportunity to conserve a genetic heritage of global importance. Both ecological and social-economic conditions can drive the choice of farmers, especially of smallholders, in maintaining a large portfolio of crop varieties that can ensure a good level of productivity under unfavorable and changing conditions. There is clear evidence that abiotic stress determines a higher richness of intra-specific diversity in the form of local varieties grown by farmers living in climatically unfavorable areas. The results for the studied ecoregions follow the same trend, with ecoregions with harsher conditions displaying a higher positive correlation with diversity. Mild environments such as the Central Asian riparian woodlands show an unexpectedly lower diversity than other harsher ecoregions. Ethno-linguistic groups also have an effect on the level of varietal diversity used, related both to historic nomadic practices and a culture of harvesting wild fruit and nuts in mountainous areas. Home garden management systems host a higher diversity compared to larger production systems, such as orchards. The integration of the varietal diversity in home gardens into national research and extension systems could facilitate the national conservation and development of fruit and nut trees for the benefit of farmers living in the diverse environmental habitats of Central Asia.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/world5010002/s1. Table S1. Description of the selected agroecosystems and project sites in the region; Table S2. Characteristics of Households (HH): crop, management space, country, agroecological zone, ethnic groups, and ecoregion; Table S3. Varietal diversity at household level; Table S4. Variety names and types per crop at project level; Table S5. Model selection table.

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