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Non-native flora changes in rural gardens of China: the role of tourism

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Abstract
Human cultivation facilitates the naturalization and subsequent invasion of non-native plant species through, for example, protection from predators or reducing environmental stochasticity. With the development of tourism, non-native plant species have been increasingly introduced into rural home gardens for landscape greening and amenity planting. However, few studies have examined non-native flora in rural home gardens, and in particular the importance of tourism in determining changes of garden non-native flora has not been scrutinized. In this study, we investigated non-native plant species in 135 home gardens across five rural tourism villages in tropical China. Attributes related to garden or household characteristics were also collected through interviews and questionnaires. A distance-based redundancy analysis was then performed to reveal the relationships between the non-native species composition and garden attributes. A total of 338 non-native plant species were recorded in the surveyed gardens. Among them, the majority (63%) were ornamentals, whereas 19% were for nutritional uses and 12% were spontaneous weeds. Gardening preference and distance to tourist attractions governed the non-native compositions, with gardens preferring cultural (ornamental) cultivation or gardens close to tourist attractions having more non-native species. These results highlight an increasing role of tourism in promoting non-native cultivation in rural gardens. Recommendations for species risk assessment, trade and supply regulation, and proper garden management are provided to help harness plant invasion along tourism development in rural China and other regions around the world.

Keywords Rural tourism · Home garden · Non-native plant · Species composition · Ornamental use · Southwest China

1 Introduction

Home gardens, also known as private gardens, domestic gardens, or residential yards, are one of the oldest forms of land use in the world's arable regions [1]. They represent reservoirs of cultivated resources for satisfying the immediate needs of household members [2]. In addition, home gardens are acknowledged for their in situ preservation of biodiversity and genetic resources, notably for crop breeding and medicinal plants [3]. Likewise, home gardens are believed to conserve traditional knowledge that helps households maintain their culture or identity [4]. Consequently, home gardens serve as interesting sites for researchers to examine the relationships between people and nature, particularly for studies of human preferences or behaviors related to species selection, persistence, and ultimately the assembly of species communities in human-dominated landscapes [5].

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Explicit recognition of home garden's functions for the last few decades has resulted in a growing body of environmental literature specifically related to garden biodiversity [6, 7]. In contrast to the traditional notion that considers home gardens ecologically impoverished habitats, recent studies have recognized that home gardens can reach surprisingly high levels of biodiversity, most visible in the form of high plant species richness [8, 9]. In some parts of the world, home garden plant richness can even outnumber the surrounding semi-natural and natural habitats [10–12].

This manner of high plant diversity could be caused by various biophysical and socioeconomic factors, including geographic location, climatic condition, socioeconomic status, and cultural norms. However, the most notable cause is perhaps attributed to the intrinsic nature of home gardens as intensively managed areas where humans make decisions about habitat structure and species inclusion [13, 14]. Thus, garden plant species can be drawn from a much larger species pool, where species may be sourced locally or potentially even globally via plant nurseries, florists, or agricultural supply stores [15]. Moreover, home gardening efforts (e.g. watering, fertilizing, use of herbicide or pesticide) can also help selected plant species enjoy nearly optimal levels of nutrients and protection from unfavorable environmental conditions that might be different from their native ranges [16, 17].

As a consequence of human introduction and management, large numbers of home garden plant species are non-native (i.e. exotic in origin), and they often constitute a substantial proportion of garden flora. This phenomenon has been repeatedly shown by recent investigations across the world, both in urban and rural spheres. For example, in the United Kingdom, the flora of home gardens in five surveyed cities contained approximately 70% non-native plants [11]. In the United States, an average of 67% of garden plant species were non-natives in seven major cities that represent different ecological biomes and major climatic regions across the US [7]. As in urban areas, the dominance of non-native plants appears to be a common feature in the home gardens of rural areas, although usually in smaller proportions. For instance, in Bangladesh, rural gardens across six regions had 41% of plants that were not native to the Indian subcontinent [18]. In the African country of Benin, nearly 52% of garden plants across 360 villages were recorded as non-natives [19], thereby matching findings from rural studies in Sri Lanka [12] and southern Mexico [20].

In addition to the differences in proportions, the floristic compositions of garden non-native plants in urban and rural settings are typically also divergent. In urban localities, where basic staple and vegetable needs are primarily purchased, home gardening is marked by a preference for ornamental and aesthetic plants [21, 22]. However, in rural areas, where easily accessible or affordable retail markets are often lacking, home gardeners often pursue self-sufficiency and concentrate on foodstuffs (e.g. vegetables and fruits) or other supportive plants (e.g. medicine, fodder, or fuel) [23, 24]. This type of subsistence garden can be particularly common in lower-income households or remote rural communities [4, 12].

Beyond being considerably beneficial to households, intensive cultivation of non-native plant species in home gardens could also cause ecological or conservation problems both at the local and broader scales. First, non-native garden vegetation is likely to play a critical role in determining the abundance of the surrounding wildlife (e.g. birds, butterflies, bees, and wasps). A study of six pairs of home gardens within a suburban area of Pennsylvania, USA, found that native planting significantly increased butterfly and bird diversity compared to conventionally managed non-native gardens [25]. This result is supported by research in experimental gardens that showed native pollinating insects rarely visit non-native plants [26]. Hence, the presence of non-native plants can reduce food resources for garden fauna and compromise their associated ecosystem services (e.g. pollination or seed dispersal) [27].

Second, some garden species can escape, establish, and even become invasive to surrounding environments through wind [28], birds [29], or even garden waste dumping [30]. For example, dense stands of non-native knotweeds (*Fallopia* spp.) that were initially introduced for ornamental uses and then escaped from home gardens now invade natural vegetation in riparian habitats in Europe, resulting in decreased native plant and invertebrate diversity [31]. In addition to the invasion risk, new escapees can also interbreed with native species and transfer genes between congeneric species, leading to a loss of genetic distinctness of the local native flora [32]. For rural areas, the escapees or genetic modification of local landraces could directly affect staple food production in surrounding farmlands [17], which may render rural households or communities more vulnerable to shocks from economic distress or climate change [33].

In China, rural tourism has been promoted since the 1990s. Particularly in the last decade, rural tourism has been recognized as a preferred strategy by the government for poverty alleviation and rural revitalization [34]. Nationally, a total of 1400 villages and 198 towns have been designated as important destinations for rural tourism by the *Ministry of Culture and Tourism of China* in the last decade. These villages or small towns are located predominantly in or around poverty-stricken regions and feature a dependence on agricultural activities and abundant tourism resources. Such pro-poor tourism initiatives (together with other poverty alleviation measures) have caused a tremendous reduction in rural poverty levels in recent years [35]. In some regions, tourism growth has generated substantial economic benefits for rural communities, leading to improved infrastructure (e.g. water, roads, and telecommunications) as well as better living standards (e.g. better houses, large gardens, and rural amenities) [36, 37].

Meanwhile, since the *Open Door Policy* in 1978, with the unprecedented acceleration of international trade, transportation and human mobility, an increasing number of non-native plant species (> 14,710) have been brought into China [38], and currently more than 403 of them have become invasive at the local and national scales. This has resulted in a significant burden on native species, public health, agriculture, and other economic sectors [39]. Among them, nearly 60% (238 species) were intentionally introduced into China, notably as ornamental (139 species), fodder (54 species), and for medicinal purposes (31 species) [40]. Additionally, in recent decades, many invasive species have expanded their range from initial entry points (primarily near coasts or border areas) to the vast inland areas of China along with domestic economic activities [41, 42].

For the recognition of extensive tourism development in rural China and potential invasions of garden non-natives to rural environments, clarification is needed on how tourism invokes the dynamics of garden non-native plants in rural communities of China. In this study, we chose Dai's home gardens in tropical Southwest China as an example, and especially addressed the following two research questions to improve our knowledge regarding rural tourism and garden non-native cultivation: (1) What non-native species are currently cultivated or grown in home gardens of rural tourism communities? (2) Which are the likely important factors that determine non-native species composition in these gardens? Regarding the first question, we expected an increased share of ornamental and aesthetic plants in gardens due to the involvement of rural tourism, leading to a decline in food and nutritional plants in these gardens. For the second question, our expectation was that tourism-related factors (e.g. geographical proximity to a tourist attraction, length of tourism operation, and gardening preference changed by tourism involvement) would exert a greater influence on non-native species composition of gardens, while basic garden attributes (e.g. garden area and age of garden) may change less. We expect our findings will provide management implications for rural communities with tourism development both in China and other regions around the world. More importantly, this study is expected to stimulate greater research interests to address the link between garden cultivation and rural invasion. We believe that with the development of common global learning, invasion due to garden cultivation can be properly prevented or harnessed in most rural communities.

2 Materials and methods

2.1 Study area

This study was conducted in Xishuangbanna, an autonomous prefecture of the Dai people in the southern end of Yunnan Province that borders both Myanmar and Laos and is adjacent to Thailand and Vietnam (Fig. 1). The Dai people exhibit significant cultural cohesion, unified by language (*Tai Lue*, a local dialect of the Thai language) and religion (*Theravada Buddhism*), and have cultural institutions (e.g. intermarry, folk costumes, and vegetarian cuisine) that distinguish them from other ethnic groups in China. Further, the Xishuangbanna region is characterized by rich biodiversity and is noted for the largest rainforest in China and diverse flora and fauna given its tropical humid climate and remoteness from central China until recent decades.

Ganlanba (21°51′11"N, 100°56′35"E, 542 m a.s.l.), also known as the *Olives Dam*, is located approximately 35 km southeast of Jinghong City (the capital city of Xishuangbanna). Ganlanba is a small, cultivated basin along the Lancang River (*Mekong*) and one of the important Dai-dwelling areas in Xishuangbanna. Five well-preserved Dai villages (*Manjiang*, *Manchunman*, *Manga*, *Manzha,* and *Manting*, Fig. 1) and hundreds of Dai families have lived there for generations. With Buddhist temples, stilted bamboo/wood houses, and tropical plants, these villages become 'open-air and living history' museums for visitors to experience the culture and authentic lifestyle of the Dai people.

Traditionally, all the villagers are farmers who have been practicing shifting cultivation with paddy rice, sweet corn and several cash crops (e.g. rubber, tea, banana and pineapple). In addition to field agriculture, Dai people allot small parcels of land (< 0.5 ha) around their houses as home gardens, primarily for vegetables, fruits, or medicines that are not conveniently obtained from fields or markets to accommodate their daily needs. Since the late 1990s, rural tourism has been promoted by the local government in response to the rapid expansion of China's domestic tourism market, with the primary goal of generating alternative sources of cash income. The Buddhist temples as traditional attractions are well restored, and a water-splashing square and an affiliated Dai dance hall are also established (Fig. 1). In addition, loans and subsidies are regularly offered to villagers to assist in operations of small tourism businesses (e.g. guestrooms, food services, or souvenir stands). To further strengthen the image of the 'garden village', efforts for garden greening and

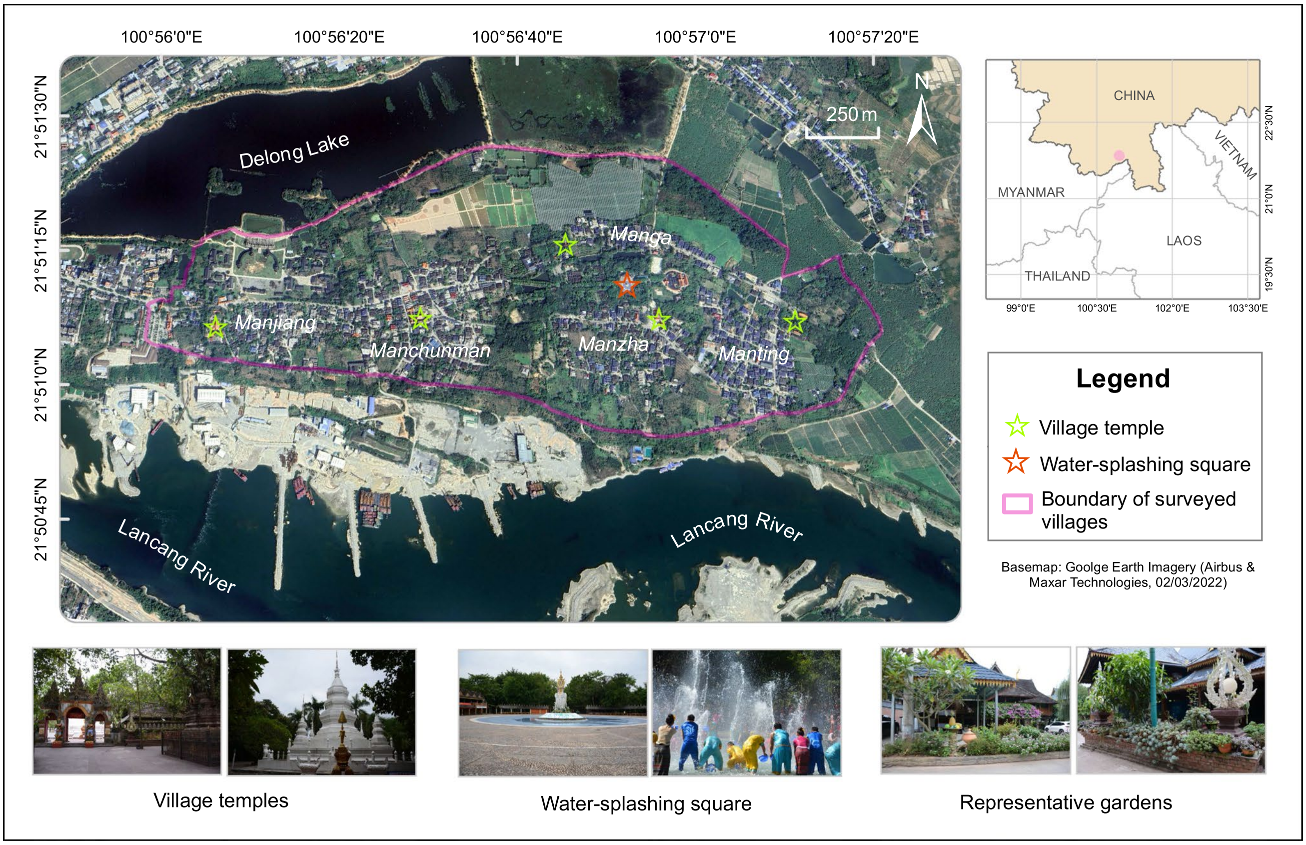

Fig. 1 Location map and tourist attractions of the surveyed villages. The photos at the bottom show the ground truths of the village temples (left), the water-splashing square (middle), and the representative gardens (right) encountered throughout the survey

amenity planting are encouraged by the local government as well. In response to this socioeconomic transition, villagers' home gardens and floristic compositions have gradually evolved along with tourism involvement in recent decades.

2.2 Garden selection

A home garden was understood in our study to be a vegetated area surrounding a house. In the case of the Dai people, houses are always detached as a single unit, and gardens are partially or fully fenced, with nutritional, medicinal, or other supportive plants grown in the gardens. To avoid sampling bias, we adopted a systematic sampling scheme and selected one of three successive gardens according to the number of houses inlaid on the doors or garden fences. Prior to the survey, the householder was contacted for permission to access the garden. When access to a selected garden was not possible, we moved to adjacent gardens until access was granted. To facilitate plant identification and questionnaire surveys, data collections were conducted from July to August in 2020 and 2021, when garden plants are in the peak growing season and householders are more likely to stay at home due to the monsoon rain. The survey resulted in 135 gardens being investigated, which accounted for 37% of the total 363 gardens across five villages at Ganlanba.

2.3 Garden flora survey

In each surveyed garden, we recorded all taxa of vascular plants present in the garden, including plants in pots, tubs, or ponds. Individual plants were identified to the lowest taxonomic level possible (i.e. genus, species, subspecies, variety, or cultivar). Because some plants could not be identified in the field, we photographed or made voucher specimens for later identification by experienced botanists at Yunnan University.

The scientific nomenclature of plants followed the *World Flora Online* (http://www.worldfloraonline.org) and was complemented by the *Flora of China* (http://www.iplant.cn) and Lin [43] for varieties or cultivars unavailable in the WFO database. All species were then classified as native or non-native to China flora according to He [44], Ma [39], and Ma and Li [45]. In case there was a controversy regarding the species origin, we verified the species native range from the *Plants of the World Online* (https://powo.science.kew.org). Furthermore, plants were classified into cultivated species or spontaneous species (i.e., weeds) by consulting householders. Cultivated species are plants intentionally introduced or maintained by households for different purposes (i.e. nutritional, medicinal, ornamental, religious, and other supportive uses). The species that did not have roles fell into any utilitarian category were classified as spontaneous and weedy species.

2.4 Garden variable collection

When the plant survey was completed, we invited the householder (or the member who was responsible for garden management) to participate in an interview and complete a short questionnaire. The first portion of the questionnaire was designed to obtain garden/household general information and economic profiles, and the subjects were as follows: (1) garden area; (2) age of garden; (3) household income; (4) proportion of garden plants sold (i.e. fresh/preserved fruits, vegetables, or flavoring plants supplied to food services or restaurants for tourists or sold to local markets); and (5) whether the household directly participated in tourism operations (e.g. guestrooms, food services, or souvenir stands) and the beginning year of tourism operation if ever.

The second portion of the questionnaire related to the householders' knowledge and attitudes towards garden non-native plants. The householders needed to answer the following: (1) number of non-native species present in the garden; (2) name of non-native species in the garden (to verify the answer from the previous question); (3) type of non-native plant most favored (1-nutritional; 2-medicinal; 3-ornamental; 4-religious; 5-others, e.g. timber, fodder, fuel, or fiber); and (4) source of non-native plant (1-relative, friend, or neighbor; 2-local florist or nursery; 3-neighboring regions/countries such as Myanmar, Laos, Thailand, or Vietnam; and 4-other sources like the internet trade).

In addition to the questionnaire, data on other variables that might influence the composition of non-native flora in the surveyed gardens were collected. The distances from the garden to tourist attractions (i.e. the water-splashing square and the village's Buddhist temple) were measured using Google Earth Pro (version 7.3.6). The gardening preference of the household, which could influence the introduction or removal of garden plants, was also considered and defined as the proportion of all cultivated plants in the garden, with high ratios implying active planting, frequent weeding or watering to maintain selected utilitarian plants in the garden. To know which type of utilitarian plant contributed more to garden flora differences, we further divided the cultivated plants, based on their essential functions, into supportive (e.g. food, medicine, wood, fodder, fuel, o fiber) and cultural (e.g. ornamental or religious) plants.

2.5 Data analysis

All statistical analyses in this study were performed using R 4.3.0 [46]. We first assessed the adequacy of our sampling effort for garden plants. Species accumulation curves among the 135 surveyed gardens were established using the *specaccum* function in the *vegan* package [47]. Based on the shape parameters of the curves, we also extrapolated the total richness of garden species that could potentially occur at Ganlanba (i.e. the gamma diversity) using the *specpool* function in the same package. The Chao and Jackknife1 methods were chosen to yield less biased estimations based on nonparametric extrapolation [48, 49].

To reveal the compositional pattern of the garden plants, a data matrix with the presence/absence of non-native species in each surveyed garden was created. Further, the compositional differences of gardens (i.e. the beta diversity) in the sampled villages were compared via multivariate analysis of variance (MANOVA) using the *adonis2* function in the *vegan* package. Then, a distance-based redundancy analysis (db-RDA, Bray–Curtis distance) was performed to examine the relationships between garden attributes and non-native species composition. Whereas RDA is a constrained ordination method applicable to the situation when environmental variables respond in a linear manner to the changes in community composition [50], the distance-based RDA is an extension of RDA to handle various distance (or dissimilarity) measures rather than the Euclidean distance in the standard RDA [51, 52] (also see explanation in Appendix S1). The db-RDA was performed with the *dbrda* function in the *vegan* package.

The garden attribute variables included in the db-RDA were classified into four groups: (1) garden/household general character (garden area, age of garden, and household income); (2) garden economic function (proportion of plants for sale and number of years in tourism operation); (3) distance/neighborhood attribute (distance to water-splashing square and distance to village temple); and (4) the owner's knowledge and gardening preference (number of non-native species correctly identified by the householder, the proportion of supportive plants cultivated, and the proportion of cultural plants cultivated in the garden).

To reduce the chances of overfitting in the db-RDA, multicollinearity among the selected garden attribute variables was assessed with the variance inflation factor (VIF) using the *vif* function in the *car* package [53]. VIF values above 10 indicate variables functionally intercorrelated with others and should be avoided in db-RDA. To quantify the contributions of a single variable as well as a group of variables after the db-RDA, the relative importance of these variables was examined by applying a hierarchical partitioning analysis using the *rdacca.hp* function in the *rdacca.hp* package [54].

3 Results

The accumulation curves for the recorded species (non-native and overall) from the 135 surveyed gardens are shown in Fig. 2. Two curves are shown in similar forms with signs of approaching the asymptotes and narrow gaps (< 15%) from the extrapolated total richness, which collectively indicated that 135 gardens was a reasonable sample number to detect the garden plant species diversity in the surveyed communities [48].

A total of 575 species were found in the 135 surveyed gardens. Among them, 338 species (298 cultivated and 40 spontaneous; see Appendix S2) from 232 genera and 75 families were not native to China, which accounted for 59% of the garden plant species in total. Out of these non-natives, 60 species were identified as nationally invasive species in China, and 131 species were classified as invasive species elsewhere in the world.

The plant families with higher numbers of alien species included Crassulaceae (38), Asteraceae (30), Asparagaceae (26), Euphorbiaceae (16), and Araceae (15), followed by Fabaceae (13), Apocynaceae (12), Amaranthaceae (11), Cactaceae (11), and Solanaceae (11). For individual species, the majority (60%,) were distributed in less than 10 gardens, with a considerable proportion of singleton (16%), doubleton (10%), and tripleton (7%) species. In contrast, 12 plants had relatively high garden occupancies and were found in more than half of the surveyed gardens (Table 1).

The non-native species originated primarily from South America (40%), Africa (19%), North America (18%), and Tropical Asia (12%). Most species (63%) were planted as ornamentals, although nutritional plants (19%) and weeds (12%) were also common. More than 81% of the species were perennial plants (largely forbs, succulents, trees, and shrubs), while annual or biennial forbs, vines, and graminoids accounted only for 19% of the garden non-natives.

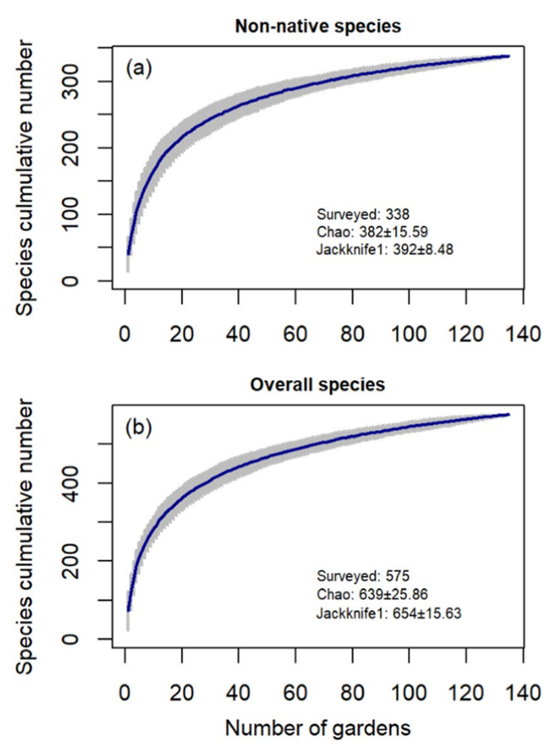

Fig. 2 Species accumulation curves for the non-native species (**a**) and overall species (native and non-native) (**b**) in the 135 sampled Dai's gardens. The total extrapolated richness for each group was estimated using the Chao and Jackknife1 methods based on the shape parameters of the species accumulation curves

Table 1 Non-native species distributed in more than half of the 135 surveyed gardens

Species	Utilitarian role	Invasive status		Number of gardens
		Global	China	
Pilea microphylla	Weed	Y	Y	111
Cymbopogon citratus	Nutritional	Y		106
Artocarpus heterophyllus	Nutritional	Y		104
Oxalis corniculata	Weed	Y		103
Chromolaena odorata	Weed	Y	Y	100
Synedrella nodiflora	Weed	Y	Y	91
Carica papaya	Nutritional			88
Citrus × aurantiifolia	Nutritional			84
Ageratum conyzoides	Weed	Y	Y	79
Portulaca umbraticola	Ornamental			77
Euphorbia milii	Ornamental	Y		71
Pouteria campechiana	Nutritional			70

All the gardens had non-native species, with numbers varying from 10 to 79 and averaging 38.96 ± 12.77 species per garden (compared to 32.21 ± 11.52 native species/garden). The non-native richness values among the gardens of five villages were not significantly different ($F_{4,130}$ = 0.5340, p = 0.711, Fig. 3a), while the non-native compositions of the gardens were significantly different among the sampled villages ($F_{4,130}$ = 3.6579, p < 0.001). The gardens in *Manga* village were more diverse compared to gardens in the other villages (Fig. 3b). A closer examination indicated that this variation nearly equally resulted from cultivated species and spontaneous species, although spontaneous species had a slightly greater accountability (Table 2).

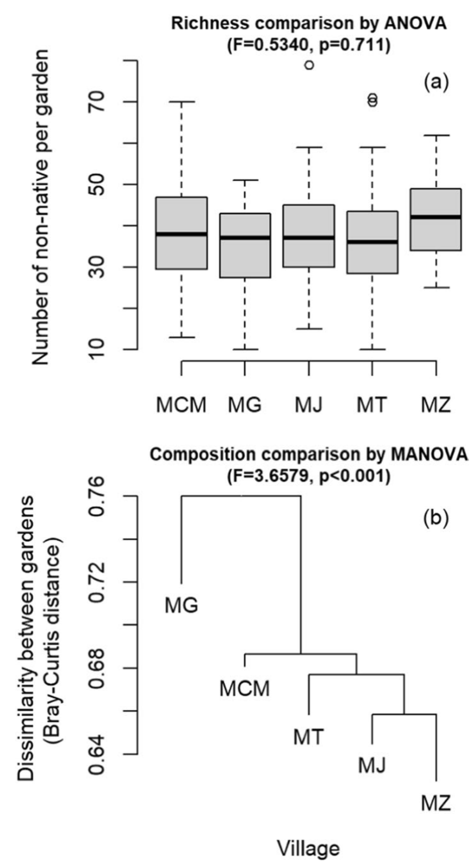

Fig. 3 Comparisons of the garden non-natives richness (**a**) and composition (**b**) of gardens among the five surveyed villages. ANOVA refers to an analysis of variance that compared the difference in the non-native numbers between gardens, while MANOVA refers to a multivariate analysis of variance that compares the compositional dissimilarity or distance between gardens. The village names are abbreviated as *Manchunman* (MCM), *Manga* (MG), *Manjiang* (MJ), *Manting* (MT), and *Manzha* (MZ)

Table 2 Results of the multivariate analysis of variance (MANOVA) showing garden compositional differences between cultivated plants and spontaneous weeds among the surveyed villages

Species type	Item	*Df*	Sum. Sq	*F* value	*P*
Cultivated	village	4	3.40	3.2679	= 0.001
	residuals	130	33.81		
Spontaneous	village	4	2.4379	4.0804	< 0.001
	residuals	130	19.4174		

The results of the *vif* function reported no multicollinearity between the selected garden variables (*vif* values < 3, Appendix S3). Thus, all variables were included in the ordination analysis. The db-RDA indicated that five important axes (explaining > 5% of the variance) together accounted for 83.54% of the fitted variation, among which the first two ordination axes were relatively dominant (Appendix S4). The first axis accounted for 42.49% of the total species variation and was primarily correlated with gardening preferences (Fig. 4). The second axis explained 15.05% of the variation and was well related to the distance to the square or temple. The variance partitioning results also validated the patterns observed in the ordination biplot diagram. This meant attributes related to gardening preference and distance to tourist attraction governed the fitted variations, while attributes related to the garden economic function (e.g. number of years in tourism operation and proportion of garden plants for sale) as well as general characteristics (e.g. household income, garden area, and garden age) had relatively small to marginal effects on the species compositional differences among the surveyed gardens (Table 3).

According to the correlations among garden attributes shown in Fig. 4, households that preferred more cultural plants had higher incomes and longer years for operating tourism businesses. We could also identify more non-native plants in their gardens, but they often had smaller garden areas and younger-aged gardens. For households that primarily used gardens to produce supportive plants, the opposite patterns were recognized. Meanwhile, gardens distant from the water-splashing square, which is a concentrated tourist attraction among the five villages, were found to be older and larger, while gardens near the square were much newer and smaller. Households far from the Buddhist temples, which are scattered tourist attractions among the villages, sold more garden plants to pursue economic returns than households near the temples. In summary, households further from tourist attractions (either the square or the temple) tended to have larger garden areas and preferred more supportive plants in their gardens, while households close to tourist attractions had smaller gardens and more likely to have cultural plants in their gardens.

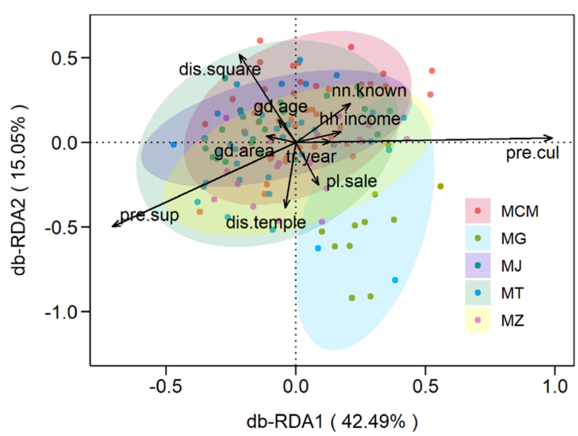

Fig. 4 Distance-based RDA ordination biplot showing the relationships between the non-native species composition and garden attributes in the surveyed gardens. The attribute variables are indicated by the black arrows pointing in the direction of increasing values and include *gd.area* (garden area), *gd.age* (age of garden), *hh.income* (household income), *pl.sale* (proportion of garden plants for sale), *tr.year* (number of years in tourism operation), *dis.square* (distance to water-splashing square), *dis.temple* (distance to village temple), *nn.known* (number of non-native known by householder), *pre.cul* (preference to cultural plant), and *pre.sup* (preference to supportive plant). The sampled gardens are shown as colored points and grouped according to the village. The village names are abbreviated as *Manchunman* (MCM), *Manga* (MG), *Manjiang* (MJ), *Manting* (MT), and *Manzha* (MZ)

Table 3 The relative importance of garden attributes to non-native species composition after the hierarchical partitioning analysis

Garden attribute	Independently explained (%)	Group	Jointly explained (%)
Garden area (*gd.area*)	1.28	G1-Garden/household general character	5.95
Age of garden (*gd.age*)	1.25		
Household income (*hh.income*)	3.42		
Proportion of garden plants for sale (*pl.sale*)	3.71	G2-Garden economic function	5.97
Number of years in tourism operation (*tr.year*)	2.26		
Distance to water-splashing square (*dis.square*)	10.76	G3-Distance/neighborhood	16.37
Distance to village temple (*dis.temple*)	5.61		
Number of non-native known by householder (*nn.known*)	3.82	G4-Knowledge/preference	71.71
Preference to cultural plant (*pre.cul*)	44.92		
Preference to supportive plant (*pre.sup*)	22.97		

4 Discussion

The results of this study showed that the surveyed Dai's home gardens contained diverse plant species, yet over 59% of them were non-native to China. Most garden non-natives were purposely cultivated by gardeners, and only a small proportion (12%) were of natural origin (i.e. spontaneous weeds). The results indicated that the surveyed rural home gardens, just like other home gardens in the rest of the world, show promise of possessing high non-native plant diversity [11, 12, 19]. Besides, the high proportion of cultivated non-native species in the surveyed gardens supported the results of previous studies that reported a significant anthropogenic influence on species assemblies in garden spaces [16, 55].

As we expected, non-native ornamental plants were overrepresented, with more than 63% of garden non-natives grown for aesthetic purposes. This high percentage differed considerably from that of rural subsistence gardens but matched well with urban gardens where non-native ornamentals prevail [56, 57]. Admittedly, ornamentals are not newcomers to Dai's gardens, with conspicuous wildflowers (e.g. species from Orchidaceae and Zingiberaceae) transplanted from mountains or forests near villages over generations. Meanwhile, along with the arrival of *Theravada Buddhism* in Southwest China (around 600 AD), some non-native plants (e.g. *Plumeria rubra* and *Corypha umbraculifera*) with religious as well as ornamental values from southern or southeastern Asia began to be cultivated in Buddhist temples and later found their way in ordinary Dai's home gardens. However, given the constraints posed by subsistence demands, these ornamental species historically accounted for only a small proportion of plants grown in Dai's gardens [58, 59].

The recorded high ornamental diversity suggests that the species in the surveyed gardens have changed, with non-native aesthetic plants increasing their share in Dai's gardens. Such floristic changes in Dai's gardens could threaten local nutritional supplements and food sovereignty given that garden food plants (particularly vegetables and fruits) secure all-season supplies that can meaningfully complement field staples and provide essential nutrients (e.g. minerals and vitamins) to Dai villagers [58, 60]. More crucially, the replacement of food plants will likely lead to a gradual disappearance of the amassed knowledge that underpins garden food production for local villagers [4, 61].

In addition to visual appeal and aesthetic value, two reasons were frequently mentioned by the surveyed householders to explain their recent cultivation of non-native ornamentals in gardens. First, there has been better access to ornamental resources in recent years from local florists/nurseries as well as online marketplaces (e.g. *Taobao* or *Jingdong*, among the largest online trading platforms in China), allowing local villagers to have a much wider variety of choices for garden planting than ever before. Second, non-native ornamentals are easily cultivated and require less effort for pest control and fertilization. These features save local villager labor that needed to manage their gardens given the dominance of women and older people in the actual management of Dai's gardens. The above advantages were also translated into their selection of non-natives to be introduced in their gardens, with most householders (87 cases) liking ornamentals as the most favourable plants, which greatly outweighted other types of non-native species (e.g. nutritional, medicinal, or religious) for garden introduction (Appendix S3).

The present study also indicated that most of the non-native plants currently recorded were rare and have not yet become a problem in the gardens surveyed. In contrast, a certain number of species have occurred widely and some already have become invasive in other regions (Table 1). These species could become a particular concern for the surveyed communities given the short delays between the arrival of introduced species and their successful spread in tropical regions [62]. Estimates of the propagation lag times in tropical regions average 14 years for woody plants and five years for herbaceous plants, which are much shorter times than the average lag time (> 50 years) in temperate regions [63].

The results from the variance analysis showed that the richness of non-native plants among the gardens was similar, but there was more compositional variation among the surveyed gardens (Fig. 3). The garden non-native diversity in *Manga* village varied relatively and was the most distinct from that in the other villages. This might be partially attributed to the closer proximity of many *Manga* households to farmlands than those in other villages (Fig. 1). More weedy species that have already colonized farmlands are able to find their niches in these *Manga*'s home gardens (and vice versa). Additionally, households in *Manga* village have relatively large farm sizes and tourism operations have been recently considered by most households (< 10 years). In light of the better economic conditions owing to field agriculture, households in *Manga* had a greater capacity to procure non-native plants to decorate gardens when they decided to start tourism, making their garden species pool different from that of the earlier engaged households. This was well illustrated by the presence of many non-native succulent plants (e.g. *Sedum*, *Echeveria*, and *Aeonium*), which represent a recent horticultural fashion and market priority in China and were largely found in *Manga*'s home gardens during our survey.

The results of the redundancy analysis showed that all the selected attributes influenced the floristic composition of non-natives in the studied Dai's gardens (Fig. 4). Planting preferences were identified as the most important force shaping garden non-native floras, indicating that the cultivation of selected species by householders, either cultural or supportive, tended to increase non-native differences in gardens. This reinforces the findings of previous studies that highlighted very close links between people's preference and the composition of garden flora [64]. However, when comparing the two preferences, cultural cultivation contributed more to non-native variation in Dai's gardens than did supportive cultivation (Table 3). This result was possibly because of the greater identifiable individualism among gardeners in ornamental planting decisions [56]. Additionally, two preference forces acted in a relatively counter-productive manner (Fig. 4), which may reflect that the operation of two opposite practices existed among the Dai villagers when considering garden management, namely, to evolve attractive gardens for tourism or to remain subsistence gardens for daily use.

In addition to the above, distances to tourist attractions, particularly to the water-splashing square, were also identified as influential factors in determining the non-native composition of the surveyed gardens. The proximity of an attraction represented more visits by tourists, which gave households an advantage in tourism operations. In contrast, households distant from an attraction could position themselves as product suppliers (e.g. sell fruits or vegetables to restaurants or guestrooms) or continue to sustain their livelihood merely through agriculture practices as usual. This was indicated by ornamental plants that were found to be more common in gardens near attractions compared to supportive plants in households at a noticeable distance from attractions (Fig. 4). Furthermore, we observed more floristic contrasts between the front and back gardens of households near tourist attractions. Within these households, the front gardens were more concentrated with flowers and ornamental species, while the back gardens were primarily filled with supportive plants. It can be reasonably deduced that the showy front spaces represent the desires of households for tourism operations due to their locational advantages. This feature may be also associated with the neighbor 'mimicry' effect that typically increases the likelihood gardens will be more similar in close vicinity to one another, particularly when evident economic benefits are obtained by neighbors from their attractive gardens [65].

Our study showed that perceived knowledge had limited explanatory power for non-native variations among gardens (Table 3). This may have been related to the consistently low scores of general knowledge of non-native species among Dai villagers, with an average of 3.55 species successfully identified by the surveyed householders (approximately one tenth of garden non-natives) (Appendix S3). This finding echoes the results of previous perception studies of non-natives in public green spaces as well as private gardens [66, 67]. Nevertheless, our study showed that gardeners who preferred cultural plants had relatively more knowledge about non-natives. An average of 4.4 non-native species were correctly identified by these gardeners in contrast to 1.8 species identified by gardeners preferring supportive plants. This disparity may be because cultural plants (largely composed of ornamentals) are purchased more frequently from external sources (i.e. florists, nurseries, and online markets) than from local sources (e.g. exchange among neighbors or relatives). Therefore, it could be assumed that the initial source of obtaining plants was the leading information used by Dai people to discriminate garden plant identity (native vs. non-native). On the other side, our survey revealed that more than two-thirds of the householders (96 cases) reported they seldom received formal guidance regarding non-native identification from marketplaces when they obtained plant materials. Accordingly, knowledge must be substantially improved among Dai villagers to ensure proper introduction and management of non-native species in their gardens [14, 68].

In contrast to the findings of previous analyses [69], our study did not find that garden non-natives strongly responded to household income levels. The well-known 'luxury effect', which is often applicable for explaining urban gardening patterns (characterized by rich households/neighborhoods that incorporate more diverse species into their gardens) [70], may not be pronounced in rural communities such as the Dai villages we studied, where disposable incomes are comparably equivalent across individual households (Appendix S3). In addition, previous studies have identified garden size and age of garden as good predictors of garden plant diversity [71, 72]. However, our study did not find a clear association between these factors and the non-native distribution in the surveyed Dai's gardens. Regarding the garden area, we found that the garden size near tourist attractions became smaller, but the number of non-natives did not decrease. This result may have been due to the multi-strata structure of tropical gardens that allows various forms of plants (e.g. climbing vines, lianas, epiphytes and aerophytes) to distribute throughout vertical spaces [23].

Considering the age of the garden, we also found that new gardens close to tourist attractions had greater non-native diversities. This suggested that Dai's gardens may not linearly accumulate non-natives over time, possibly because significant replacements of native nutritional plants by non-natives for aesthetic gardening only occurred over the last decade and were coupled with constant changes in market trends and plant availability. A similar situation occurred for the number of years of tourism operation, with no effect from a longer length of operation on garden non-native diversity. A plausible reason behind this result may be associated with the mixed nature of tourism operation data collected. For example, households with souvenir stands do not necessarily replant their gardens with aesthetic non-natives compared to households operating guestrooms or food services. Hence, years of tourism operation may not translate into differences in non-native diversity. As such, in the future studies attention should be paid to how the type of tourism involvement influences non-native flora in rural gardens.

Based on our results and considering tourism development in the studied communities, management efforts are required to minimize the actual and potential negative impacts of garden non-natives to the livelihoods of people and the environment. The immediate issue is related to non-natives that already exist in Dai's gardens. Screening procedures should be urgently applied to these species to compile a blacklist that uses a set of criteria derived from invasion research, such as residence time, propagule pressure, invasive elsewhere, and climatic suitability [73]. Restrictions on the cultivation and exchange of blacklist species in studied communities should be implemented after risk screenings.

Additionally, if local or online retailers continue to sell non-native plants, this could be unsurprisingly reflected in future garden flora of studied communities. Consequently, legislation is a necessary means to regulate external supplies of non-native plant materials [74]. Concern regarding loopholes around legislation have been expressed over internet trade, where websites such as *taobao.com* distribute significant supplies of non-native species to Chinese consumers [75]. Furthermore, compliance and compatibility by plant suppliers with voluntary codes of conduct should be promoted. Although implementing these practices across multiple stakeholders within the supply chain (germplasm importer, plant breeder, wholesale supplier, and retail outlet) is difficult, continuous commitment might gradually guide the industry toward positive changes (e.g. to increase native propagation and marketing).

On the other side, we suggest encouraging native plant usage instead of merely prohibiting or limiting non-native species, and this can be directly communicated at the interface of householders with village officers, rural planners, and temple clergies. Personal communication with householders during the course of our survey revealed high receptivity to native alternatives. However, the current major difficulties for native gardening are the limited market availability of natives and poor identification of non-natives. Factsheets that highlight detrimental non-natives, booklets that describe appropriate gardening practices (e.g. proper dumping of green waste), training campaigns that boost native cultivation based on indigenous knowledge, and endorsements from religious discourse can enhance knowledge about garden plants among Dai villagers.

Although this study represented a pioneering effort toward understanding the linkages between tourism and garden non-native diversity for the rural communities of China, several other perspectives that can further examine garden plant dynamics alongside rural tourism development should be considered. First, extensive surveys of garden species must be prioritized in rural tourism areas (e.g. nationally designated villages or towns), with the expectation of revealing the real magnitude of garden non-native problems across the country. Second, future research should provide a more complete understanding of the consequences arising from this emerging, potentially pervasive, non-native introduction pathway to rural environments. Presently, there is no clear information regarding non-native garden cultivation, such as the scale of indigenous knowledge that has disappeared, the number of native genetic resources lost, impacts on food production and food sovereignty, changes in garden wildlife and associated ecosystem services, and whether garden non-natives yield debts for future invasions under climate change. The increased availability of this information will support long-term and sustainable tourism development in rural areas. More importantly, this information can also contribute to the acceptance of proactive management for garden non-natives and a better understanding of cultivation-invasion mechanisms in human-dominated landscapes.

5 Conclusion

The present study demonstrated that the surveyed rural home gardens were very rich in non-native species, particularly in ornamentals, thus reflecting the important role that tourism currently plays in the dynamic process of garden flora in rural communities of China. Such change is likely to threaten food security and accelerate plant invasion in rural communities if non-native introduction and cultivation continue without any intervention. Therefore, management measures, such as species risk screening, regulation of plant suppliers, and native cultivation based on local knowledge, are recommended to prevent or reduce negative impacts on rural livelihoods and environments. Moreover, future research efforts should scrutinize the socio-economic and environmental consequences of garden non-native planting, with the expectation of promoting better-informed and sustained development of rural communities both in China and around the world.

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Data availability The authors declare that the data supporting the findings of this study are available within the paper and its supplementary information file. Should any raw data files be required in another format, they are available from the corresponding author upon reasonable request.

Code availability The codes for the data analysis are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Approval was obtained from the ethics committee of Yunnan University. The procedures used in this study adhere to the tenets of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent was also obtained from each participant. All participants agreed for their data to be used anonymously for the purposes of research.

Consent for publication Not applicable.

Competing interests The authors declare that they have no competing interests.

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