

Drivers for switching from gathering wild paddy field plants to growing them in gardens as vegetables in the Lao People's Democratic Republic

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Abstract

Recently, people have started growing wild vegetables in mainland Southeast Asia despite the abundance of domesticated ones. In this study, we analyzed the drivers for this trend by targeting wild paddy field plants in the Lao People's Democratic Republic. Surveys were conducted on the use, domestication status, and market status of plants, and cultivation skill of the growers in Vientiane Municipality/Province and Houaphan Province, by targeting 171 market vendors and 54 growers, in 2013–2019 and 2022. A

total of 31 paddy field plants were used as vegetables, of which 7 were grown. *Centella asiatica*, *Limnophila chinensis*, *Limnophila geoffrayi*, and *Houttuynia cordata* have been grown since the 2000s for selling at local markets, and because of demand for safe and healthy vegetables, time saved in traveling to harvesting sites, or ease of cultivation. The possible drivers for growing them were the preference for wild foods in Lao dietary culture, emerging concerns about agricultural chemical use on commercially produced vegetables, increased trade of wild plants at local markets, the ease with which these plants can be vegetatively propagated, and their resistance to pests and diseases. The results of this study have implications for food security, plant conservation, and domestication research.

Keywords: dietary culture, domestication, food preference, local market, wild edible plants

Introduction

Vegetables, as well as herbs and spices, play a significant role in the mainland Southeast Asian diet by adding flavor and color to dishes (Auer 2011; Davidson and Davidson 1981; Jacquat 1990; Tanaka and Ke 2007). In addition to common domesticated varieties, Southeast Asian food plants include wild and semi-wild plants gathered from forests, upland fields, paddy fields, and grasslands around settlements (e.g., Greijmans et al. 2007; Jacquat 1990; Tanaka and Ke 2007; Vidal 1959). Many of them are known to have medicinal properties (Greijmans et al. 2007; Tanaka and Ke 2007).

Recently, people have begun to plant wild vegetables in home gardens or agricultural fields despite the abundance of domesticated ones in mainland Southeast

Asia. Greijmans et al. (2007) showed that a variety of wild vegetables were planted and used in the Lao People's Democratic Republic (Lao PDR). Many types of vegetables grown in home gardens in Vietnam (Trinh et al. 2003) and Thailand (Srithi et al. 2012) are listed in the literature as wild plants (Ho 1999–2000; Santisuk and Larsen 1997–2012; Smitinand and Larsen 1970–1996), which suggests that they were initially transplanted from wild habitats. In Southwestern China, which neighbors mainland Southeast Asia, many wild plants were transplanted from swidden fallows to home gardens as vegetables or for other uses (Fu et al. 2003).

Here one question arises: why are wild vegetables planted by those who have abundant domesticated ones? This question can be examined from the following two viewpoints: the preference for wild vegetables and the drivers for switching from gathering wild vegetables to growing them. First, as wild foods now attract increasing attention, their roles have been evaluated in terms of wild resource conservation, human health, and dietary culture (e.g., Bharucha and Pretty 2010). However, as the reason why people prefer wild foods seems to differ spatially and temporally, it should be clarified for each region, and its intrinsic environmental and cultural settings taken into account. Second, the drivers for switching to growing wild plants have long been studied by agronomists, anthropologists, and archaeologists from the viewpoint of the initial domestication, but the reason why people started to grow wild plants remained unclear (Gepts et al. 2012; Zeder 2015). The underlying reason for this practice cannot be analyzed merely by studying the ancient domestication process. It is also necessary to target the current changing relationships between plants and people who have started to grow wild plants.

In this paper, we analyzed the reasons why people have recently started to grow

wild vegetables by targeting the relationships between people and the wild herbaceous plants of paddy fields in Lao PDR. Some wild paddy field plants have been so important as to be sold at local markets as vegetables (e.g., Greijmans 2007; Kosaka et al. 2013), but the dynamic relationships between people and these plants were not well known in relation to their importance. Many wild paddy field plants are distributed throughout the Pan-Asian regions (e.g., Fried et al. 2017; Fried et al. 2018; Ho 1999–2000; Miyazaki 2016; Nishitani 2008; Ohashi et al. 2015–2017; The Forest Herbarium 2023), which enables us to compare their use and domestication status (wild or planted) among different regions and countries.

The purpose of this study was to analyze the recent trend of growing wild paddy field plants as vegetables in Lao PDR, and to address the long-disputed question in domestication research as to why people decide to begin cultivating wild-sourced plants, as well as contributing to the study of food security, plant resource conservation, and inheritance of dietary culture.

Methods

Study sites

Lao PDR is a landlocked country in mainland Southeast Asia with a population of 7,425,057 people and an area of 236,800 km², 70% of which is covered in forest, and 9% is used as agricultural land (FAO 2021) (Fig. 1). Fully 90% of rural households cultivate rice, while 47% of urban households engage in some form of agricultural production (Ingall et al. 2018).

In this study, field surveys were conducted in Vientiane Municipality/Province and Houaphan Province in Lao PDR (Fig. 1). Vientiane Municipality/Province is located on

a plain near the Mekong River, and has a population of 1,008,531 people (municipality) and 478,497 people (province), composed of mainly Lao and partly of other ethnic groups, in an area of 3,637 km² (municipality) and 12,494 km² (province) (UNFPA 2023). Vientiane Municipality and Province have 22% and 60%–70% of the rural population, respectively, and provide 32% and 70%–80% of agricultural employment, respectively (Ingall et al. 2018). The study sites, Chanthabuly, Xaythany, and Naxaythong Districts of Vientiane Municipality, and Thoulakhom and Phonhong Districts of Vientiane Province, are located at an altitude of 160–180 masl, where the mean monthly maximum and minimum temperatures are 31.1 °C and 21.8 °C, respectively, and the mean annual rainfall is 1,660.5 mm (WMO 2023). In addition to the commercial and residential areas of the city center, there are village areas with houses, paddy fields, upland fields, and forest. Paddy fields are dominated by herbaceous species of Poaceae, Cyperaceae, and Scrophulariaceae (Heckman 1974), and forest by woody species of Dipterocarpaceae, Fabaceae, and Lythraceae (Rundel 2009).

Houaphan Province is in the northeastern mountainous region of the country with a population of 316,280 people including Lao, Tai Leu, Tai Dam, Tai Deng, Khmu, and Hmong ethnic groups in an area of 17,201 km² (UNFPA 2023). The province has the highest proportion of the rural population (80%–90%) and of agricultural employment (> 90%) in the country (Ingall et al. 2018). The study sites, Xamneua District and Huameuang District, are located at an altitude of 960–1,120 masl, where the mean monthly maximum and minimum temperatures are 26.2 °C and 15.1 °C, respectively, and the mean annual rainfall is 1,444.2 mm (WMO 2023; the data are for the neighboring Xiengkhouang Province). Paddy rice cultivation is conducted in the valleys, whereas upland cultivation is carried out on the mountain slopes. Paddy fields

are dominated by herbaceous species of Poaceae, Cyperaceae, and Scrophulariaceae (Kosaka et al. 2013), and forests by woody species of Fagaceae, Magnoliaceae, Lauraceae, Theaceae, Juglandaceae, and Pinaceae (Rundel 2009).

In both regions, the staple food is rice (both sticky and normal rice), which is accompanied by vegetables (both domesticated and wild), meats (livestock, poultry, wild mammals, and birds), snakes and lizards, frogs, freshwater fishes, crabs and shrimps, mollusks, insects, and mushrooms (e.g., Auer 2011; Davidson and Davidson 1981). People obtain vegetables by gathering them in wild habitats as well as by growing them in home gardens, or buying them at the local markets. Domesticated vegetables and herbs include leaves of plants such as cabbage, pakchoi, dill, basil, and mint, as well as fruits such as chilis, eggplant, long yard beans, and tomato. Wild vegetables include leaves of *Careya arborea* Roxb. (Lecythidaceae), *Cratoxylum formosum* subsp. *formosum* (Hypericaceae), *Syzygium antisepticum* (Blume) Merr. & L.M.Perry (Myrtaceae), and paddy field plants, as well as fruits of *Irvingia malayana* Oliv. ex A.W.Benn. (Irvingiaceae), *Spondias pinnata* (L.f.) Kurz (Anacardiaceae), and *Zanthoxylum rhetsa* (Roxb.) DC. (Rutaceae) (e.g., Greijmans 2007; Luczaj 2021; Vidal 1959). Both domesticated and wild vegetables are sold at local markets without any distinction, although the species and amounts sold differ regionally and seasonally (Kosaka et al. 2013).

Study methods

Field surveys were conducted separately at local markets and households growing paddy field plants in Lao PDR. Local markets were visited in Vientiane

Municipality/Province and in Houaphan Province in August 2013, March and December

2014, September 2015, November 2016, March 2017, March and May 2018, May and August 2019, and September 2022 (Fig. 1). The vendors selling paddy field plants were interviewed by the first author with the support of a co-author about the species name, amount, price, use, and domestication status (wild or planted) of plants sold.

Gathering/harvesting location was also confirmed when the vendors themselves were the gatherers/growers, or when the vendors knew the location by communicating with the gatherers/growers or middlemen. The total numbers of vendors interviewed were 44 (Lao ethnicity) in Xaythany District, 28 (Lao) in Naxaythong District in Vientiane Municipality, 25 (Lao) in Thoulakhom District in Vientiane Province, and 74 (51 Lao and 23 Hmong) in Xamneua District in Houaphan Province during the survey period since August 2013. All the vendors were women between the age of 20 and 70 years.

In May 2018 and September 2022, households were visited to survey instances of growing paddy field plants in Chanthabuly District (Pakthang Village), Xaythany District (Phoukham, Veunkham, Latkhouay, and Nongtee Villages), and Naxaythong District (Nanyang, Nongnyao, and Tham Villages) of Vientiane Municipality, Thoulakhom District (Nanyang and Nongphongtai Villages) and Phonhong District (Tinkeo Village) of Vientiane Province, and Xamneua District (Nasakang Village) and Houameuang District (Veek Village) of Houaphan Province (Fig. 1). First, the villages selling paddy field plants to markets were selected, then nearby villages were also visited to confirm the trend of growing these plants. At each village, one to five households growing paddy field plants were interviewed on the use, reason for growing, and market status (for home consumption only, or for home consumption and/or sale at the local markets) of the plants, and the cultivation skill of the growers. After one household was interviewed, the next household was introduced to the interviewer. A

total of 43 households (30 in Vientiane Municipality/Province and 13 in Houaphan Province) were interviewed, and the participants included 41 women (36 Lao and 5 Khmu) and 13 men (11 Lao and 2 Khmu) between the age of 20 and 60 years.

Generally, a wife grows the vegetables, including paddy field plants, in a home garden for home consumption, whereas she and her husband manage their agricultural fields for selling them.

The field surveys were conducted with research permission and prior informed consent as follows. First, after obtaining research permission from the National University of Laos, Provincial and District Agriculture and Forestry Offices were visited to explain the purpose of this study. Second, with an introduction by District Agriculture and Forestry Offices, local markets and village households were visited. The authors explained the purpose of this study and about the compliance with cultural norms to the managers and vendors of the local markets, and village households growing paddy field plants.

Among paddy field plants used as vegetables at the study sites, Pan-Asian species such as *Centella asiatica* (L.) Urb. (Apiaceae), *Oenanthe* spp., *Marsilea* spp., *Limnophila* spp., *Persicaria* spp., *Pontederia* spp., and *Houttuynia cordata* Thunb. (Saururaceae) were selected to compare their domestication status and use among Lao PDR (Vientiane Municipality/Province and Houaphan Province), southern Vietnam (Mekong Delta: Ban and Duc 1994; Tanaka and Ke 2007), southern China (Yunnan Province: Miyazaki 2016; Nishitani 2008; Xu et al. 2004), and central Japan (Kinki region: Ohashi et al. 2015–2017).

The nomenclature for the sampled plants follows Ho (1999–2000); Royal Botanical Gardens, Kew (2023); The Forest Herbarium (2023); and World Flora Online

(2023). Voucher specimens are lodged in the herbarium of the Faculty of Forestry at the National University of Laos.

Results

A total of 31 paddy field plants were used as vegetables at the study sites (Supplementary Data Table S1). Among them, 30 species were wild and 7 were planted, 2 were for home consumption only, and 29 were for home consumption and/or for sale. At the local markets, a single bunch of paddy field plants (approximately 50–100 g, either bound by their stems or put on a plate) was sold at the price of LAK 1,000–2,000 (0.063–0.126 USD on September 16, 2022). The buyers were city dwellers with no access to agricultural fields.

In Vientiane Municipality/Province, a total of 12 species were recorded, of which 11 were wild, 5 were planted, and 4 were both. Two species were only for home consumption, and 10 were for home consumption and/or for sale (Supplementary Data Table S1). All the annual species grew in paddy fields in the rainy season except *Polycarpon tetraphyllum* (L.) L. (Caryophyllaceae) and *Glinus oppositifolius* Aug.DC. (Molluginaceae), which grew only in the dry season. The most abundant plants sold at the local markets in every season were *Centella asiatica*, *Marsilea minuta* L. (Marsileaceae), *Limnophila geoffrayi* Bonati (Plantaginaceae), and *Pontederia vaginalis* Burm.f. (Pontederiaceae). Most species were eaten fresh with soup, meat, or noodles except the following two species: *Glinus oppositifolius* was cooked to add a bitter taste in *keng paa* (fish soup), and *Limnophila geoffrayi* was boiled to add flavor in *keng noo mai* (bamboo shoot soup).

In Vientiane Municipality/Province, a total of 16 households grew *Centella*

asiatica (Fig. 2B). They started transplanting it from the nearby paddy fields to home gardens in the 2000s. The reasons for growing *Centella asiatica* were as follows: selling at local markets (12 households), demand for safe and healthy vegetables (10), and ease of cultivation (5). Among the households that recognized *Centella asiatica* as a healthy vegetable, eight mentioned that it has the medicinal property of cooling the body. One household explained that the income from *Centella asiatica* was better than rice when grown in a paddy field on convex land prone to water shortages. Another explained that carefully grown *Centella asiatica* looked more attractive than the wild ones and sold better at the local markets. A total of six households grew *Limnophila geoffrayi* since the 2000s. They said that they could save time by growing it in a home garden for frequent home consumption, and that they also used and sold wild *Limnophila geoffrayi* (Fig. 2E) gathered at the nearby paddy fields. A total of 24 households grew *Houttuynia cordata* since the 2000s (Fig. 2D). Because this species is not found in wild habitats in Vientiane Municipality/Province, it was initially transplanted from Houaphan, Xiengkhouang, or Xayabury Province by immigrants (Fig. 2C), or the first seedlings were bought at a local market. The reasons for growing *Houttuynia cordata* were as follows: selling at local markets (21 households), demand for safe and healthy vegetables (19), ease of cultivation (14), and the custom of consuming this species in the respondents' home province in northern Lao PDR (8). At Nongnyao and Nongphongtai Villages, where many households grew *Houttuynia cordata*, middlemen shipped it to the local markets, which facilitated the residents to start growing it. The growers installed sprinklers for watering *Houttuynia cordata* at the two villages. Among the households that recognized *Houttuynia cordata* as a healthy vegetable, eight households mentioned that it has the medicinal property of mitigating dizziness. They

also knew that the plant is utilized as an ingredient in Thai medicine for hemorrhoids and high blood pressure. They said that some residents did not like the strong scent of *Houttuynia cordata*, whereas others got used to consuming it as a vegetable. *Centella asiatica* and *Houttuynia cordata* were not only grown in small-scale home gardens, but also by part-time farmers in infertile agricultural fields. They said that *Centella asiatica* and *Houttuynia cordata* were perennial and easily propagated vegetatively. They are more resistant to pests and diseases, and required less labor and cost than the main leafy annual plants such as basil, mint, dill, or celery, which were cultivated by full-time farmers in the fertile riverside fields. *Eryngium foetidum* L. (Apiaceae), originating in South America, has long been cultivated, and was naturalized in paddy field levees as well. *Eryngium foetidum* has been cultivated because it is easily grown and is considered an essential herb for adding flavor in various kinds of soups, and has a high demand at the local markets. *Persicaria odorata*, native to Southeast Asia, has also been cultivated for a long time.

In Houaphan Province, a total of 24 species were recorded, of which 23 were wild, 4 were planted, and 3 were both. All species were for home consumption and/or for sale (Supplementary Data Table S1). All the species grew in paddy fields in the rainy season, and some perennial species also grew in the dry season. The most abundant plants sold at the local markets were *Centella asiatica* (Fig. 2A), *Marsilea quadrifolia* L. (Marsileaceae), and *Pontederia vaginalis* in the rainy season, whereas *Centella asiatica*, *Marsilea quadrifolia*, and *Juncus prismatocarpus* R.Br. (Juncaceae), which were often sold in combination, were the most abundant in the dry season. A popular local dish called *sup phak* (boiled vegetables) was cooked by boiling the paddy field plants with ginger and salt for flavoring. *Centella asiatica* and *Houttuynia cordata* were also eaten

fresh with soup, meat, or noodles. *Limnophila chinensis* (Osbeck) Merr.

(Plantaginaceae) was only used for adding flavor in a popular home dish, *keng noo mai* (bamboo shoot soup).

In Houaphan Province, a total of five households have transplanted *Limnophila chinensis* (Fig. 2F), which did not previously grow in that province, from the northern region of Vientiane Province since the 2000s. The reason for growing *Limnophila chinensis* was that they liked *keng noo mai* with *Limnophila* flavor. Although *Limnophila geoffrayi* offers a better flavor for this purpose, it cannot survive the cool weather in Houaphan Province. Among them, two households sometimes sold it at the local market when they harvested more than they consumed. A total of eight households grew *Houttuynia cordata* since the 2000s. The reason for growing *Houttuynia cordata* was to save time in traveling to distant harvesting sites. Three households recognized it as a healthy vegetable with medicinal properties. They also said that many people prefer wild *Houttuynia cordata* because it had a stronger taste and scent than the cultivated one. The two introduced species have been cultivated for a long time and naturalized in paddy fields as well: *Eryngium foetidum* as mentioned above, and *Nasturtium officinale* R.Br. (Brassicaceae), which originated in Europe. *Nasturtium officinale* has been cultivated because it was considered a delicious vegetable and had a high demand at the local markets, and is easily propagated vegetatively, although it can survive only at cool, wet sites.

Table 1 shows the comparison of domestication status and use of the Pan-Asian paddy field plants among the focal regions in Asia.

Centella asiatica grew wild in Houaphan Province (Lao PDR), Yunnan Province (China), and the Kinki region (Japan), and was both wild and planted in Vientiane

Municipality/Province (Lao PDR) and the Mekong Delta (Vietnam). Its leaf was used as a vegetable in these regions, and it was also consumed as juice in the Mekong Delta. Its medicinal properties and cultivation methods are described in the encyclopedia of Vietnamese (Le and Nguyen 1999) and Chinese medicine (Shanghai Scientific & Technical Publishers and Shogakukan 1985). Vietnamese and Chinese companies sell health foods and cosmetics made of *Centella asiatica* via the internet. There was no record of its use in the Kinki Region.

Oenanthe spp., including *Oenanthe linearis* Wall. in Houaphan Province and *Oenanthe javanica* DC. (Apiaceae) in other regions, grew wild in Houaphan Province and Yunnan Province, and was both wild and planted in the Mekong Delta and the Kinki region. Their leaves were used as vegetables in these regions. *Oenanthe javanica*, cultivated for more than 1,000 years in the Kinki region, is an essential ingredient of traditional dishes (Aoba 2013). This genus was not recorded in Vientiane Municipality/Province in this study.

Marsilea spp., including *Marsilea minuta* in Vientiane Municipality/Province and *Marsilea quadrifolia* in other regions, grew wild in all regions. In the Kinki region, its population drastically decreased in the late 20th century because of the improvement of water discharge and use of herbicides in paddy fields, and it is now designated as an endangered species. Their leaves were used as vegetables in all regions except Kinki.

Limnophila spp., including *Limnophila geoffrayi* in Vientiane Municipality/Province, *Limnophila chinensis* in Houaphan Province and the Mekong Delta, *Limnophila rugosa* (Roth) Merr. in Yunnan Province, and *Limnophila aromatica* (Lam.) Merr. in the Kinki region, grew wild in Yunnan Province and the Kinki region, were both wild and planted in Vientiane Municipality/Province and the Mekong Delta,

and planted in Houaphan Province. Their stems and leaves were used either as vegetables or as herbs to add flavor in soups. There was no record of such use in the Kinki Region.

Persicaria spp. included *Persicaria odorata* (Lour.) Soják in Vientiane Municipality/Province and the Mekong Delta, *Persicaria* sp. in Houaphan Province, *Persicaria barbata* (L.) Hara, *Persicaria chinensis* (L.) H.Gross, *Persicaria hydropiper* (L.) Delarbre, and *Persicaria orientalis* (L.) Spach in Yunnan Province, and *Persicaria hydropiper* in the Kinki region. They grew wild in Houaphan and Yunnan Provinces, were both wild and planted in Vientiane Municipality/Province and the Kinki region, and planted in the Mekong Delta. Their leaves were used either as vegetables or herbs. In the Kinki region, a sour sauce made of vinegar and the crushed leaf of *Persicaria hydropiper* was prepared when eating sweetfish (*Plecoglossus altivelis*).

Pontederia spp., including *Pontederia hastata* L. and *Pontederia vaginalis* in Vientiane Municipality/Province, Houaphan Province, Yunnan Province, and the Mekong Delta, *Pontederia korsakowii* (Regel & Maack) M.Pell. & C.N.Horn and *Pontederia vaginalis* in the Kinki region, grew wild in all regions. Their leaves and immature inflorescences were used as vegetables. In the Kinki region, they had been planted and used as vegetables until the Edo era (1603–1867), whereas *Pontederia korsakowii* is now designated as a threatened species for the same reason as *Marsilea quadrifolia*.

Houttuynia cordata grew wild in Yunnan Province, was both wild and planted in Houaphan Province and the Kinki region, and planted in Vientiane Municipality/Province and the Mekong Delta. Its leaf was used as a vegetable in all regions except the Kinki region, where its fresh leaf was used as a medicine to treat

pyosis, and the dried leaf for making a tea. In Yunnan Province, its rhizome was also used as a vegetable. Its medicinal properties and cultivation methods are described in the encyclopedia of Vietnamese (Le and Nguyen 1999) and Chinese medicine (Shanghai Scientific & Technical Publishers and Shogakukan 1985). Vietnamese and Chinese companies sell health foods and medicine made of *Houttuynia cordata* via the internet.

Discussion

There are more than 100 species of wild herbaceous plants recorded in paddy fields in Lao PDR (Heckman 1974; Imanishi 2021; Kosaka et al. 2006; Kosaka et al. 2013). Among them, we revealed that a total of seven species were planted as vegetables at the study sites. Transplanting wild plants to agricultural fields was an important way to ensure food security, health care, and conservation of economically significant species (Fu et al. 2003).

The results of this study suggest several drivers for switching from gathering wild paddy field plants to growing them. First, wild foods are highly valued in Lao dietary culture. In Lao PDR, both wild and domesticated vegetables have long been consumed as part of the cuisine (e.g., Auer 2011; Davidson and Davidson 1981; Greijmans 2007; Luczaj 2021; Tips 2001; Vidal 1959). The reason for the high dependence on wild foods can be partly explained by the long-term war and economic disarray in the 20th century (Duckworth et al. 1993). Those events hindered the production and distribution of domesticated vegetables, which may have promoted the consumption of local wild vegetables. Moreover, the existence of the Laotian term *phak*, which is the generic name for both wild and domesticated leafy vegetables (Kosaka et al. 2013), indicates that the

use of wild vegetables is a part of Lao dietary culture. This view is reinforced by the fact that the recipes by Chaleunsilp Phia Sing, who was the Master of Ceremonies and Chef at the Royal Palace at Luang Prabang in the early 20th century, described the use of multiple wild vegetables (Davidson and Davidson 1981). Lao people have enjoyed the characteristic flavors, often bitter, sour, or astringent, of wild vegetables, which domesticated ones lack.

Second, a preference for wild vegetables increased alongside growing health concerns. In the 2010s, the local media reported a health problem due to the heavy use of agricultural chemicals in banana plantations in Lao PDR (RFA 2019). The media report reminded people of the importance of *thammasat* foods (wild foods), or crops produced without applying agricultural chemicals. During the same period, because of media advertising Thai and Vietnamese medicine made of *Centella asiatica* and *Houttuynia cordata*, many Lao city dwellers re-evaluated them as safe and healthy vegetables.

The increasing demand for wild vegetables mentioned above accelerated the trade of paddy field plants at the local markets. The more people buy wild vegetables at these local markets, the more farmers grow them for cash income (Xu et al. 2004). When the number of farmers growing these plants in a village reached a certain number, a distribution network was established among growers, middlemen, and sellers, which facilitated new households to start growing these vegetables. In Lao PDR, the buyers of paddy field plants are city dwellers with non-farm jobs, and those who have no access to agricultural fields. This trend indicates that socio-economic changes, such as rural-urban migration, more opportunity for non-farm jobs, and transforming agricultural fields to other land uses, had indirect effects on the practice of growing paddy field

plants, which could not be analyzed in this study. A socio-economic driver for growing wild plants in Yunnan Province, China, was reported by Fu et al. (2003), where useful wild plants in the fallow land of swidden farming areas were relocated to home gardens because they were less available after sedentary farming was introduced.

The ecological traits of wild paddy field plants, such as being easy to propagate vegetatively and resistant to pests and diseases, were also related to the drivers for switching to growing them. These traits enabled the part-time farmers to start growing them, saving them time and money. However, *Marsilea* spp. and *Pontederia* spp., equally popular vegetables with the same ecological traits, were not planted at the study sites. The reasons for this were considered as follows: first, their vigorous growth in wild habitats exceeded the pressure of frequent gathering; second, they require much water to grow, and it was difficult to provide inundated environments outside of paddy fields. There were more than 20 *Limnophila* species in Lao PDR (The Forest Herbarium 2023), but only two species, *Limnophila geoffrayi* and *Limnophila chinensis*, were selected for growing because their flavors matched local dishes. The results of this study supported Sauer's (1952) description of the characteristics of plant use in mainland Southeast Asia, such as the significance of vegetatively propagated plants and preferences regarding spices and herbs.

Limnophila chinensis is grown in Houaphan Province and *Houttuynia cordata* in Vientiane Municipality/Province because there are no wild populations of these species in either of these regions. As a result, they expanded their distribution via transplantation by farmers, as did *Centella asiatica* in the Philippines (Merrill 1912) and *Oenanthe javanica* in Indonesia (Steenis 1948–1954). *Eryngium foetidum* was cultivated and naturalized since its introduction from South America after the 17th

century (Burkill 1936), and so was *Nasturtium officinale* since being introduced from Europe in the 19th century (Tips 2001).

The results of this study have implications regarding the debate about the causal factors for domestication. Two alternative explanatory frameworks for initial domestication, the diet breadth model (DBM) of optimal foraging theory and the cultural niche construction (CNC) explanatory framework, have been suggested. DBM predicts that foragers will always choose resources with higher net energy returns, after search and processing costs, over lower-return resources. Under DBM rules, foragers will only opt for resources with delayed returns (e.g., those that require tending over a growth cycle) when resources that provide immediate returns are no longer as plentiful. DBM casts efforts to modify environments that lead to domestication as adaptive responses to resource depression. Conversely, the CNC explanatory framework, derived from macroevolutionary theory, argues that long-term commitments to niche-constructing activities required for domestication are more likely to occur in stable or resource-rich environments (Zeder 2015). The results of this study support the latter because people with enough access to various foods spontaneously started to grow wild paddy field plants to improve their diet in the context of their local cultural and environmental settings. In Lao PDR, people recently started to also grow many wild woody or climbing vegetables, such as *Oroxylum indicum* (L.) Kurz (Bignoniaceae), *Senegalia insuavis* (Lace) Pedley (Fabaceae), *Cyclea barbata* Miers (Menispermaceae), *Tiliacora triandra* (Colebr.) Diels (Menispermaceae), *Melientha suavis* Pierre (Opiliaceae), and several species of bamboo and rattan (Greijmans et al. 2007; NAFRI 2023). The results of this study can be regarded as evidence supporting a broad trend of niche construction in contemporary Lao PDR.

Although several varieties were distinguished within *Persicaria hydropiper* and *Oenanthe javanica* in Japan (Aoba 2013) and within *Centella asiatica* and *Houttuynia cordata* in Vietnam (Tanaka et al. 1997), the domestication syndrome of paddy field plants has not been detected in Lao PDR to date. Genetic analysis is necessary to prove the effect of human selection on the plants' morphological and physiological traits.

Conclusions

There are more than 100 species of wild paddy field plants in Lao PDR, of which 31 were used as vegetables at the study sites. Most of them were eaten fresh, and only two were cooked to add flavor in soups. In Vientiane Municipality/Province, *Eryngium foetidum* and *Persicaria odorata* have long been cultivated, and *Centella asiatica*, *Limnophila geoffrayi*, and *Houttuynia cordata* were grown since the 2000s. The main reasons for the recent practice of growing them were selling at the local markets, demand for safe and healthy vegetables, time saved in travelling to distant harvesting sites, or ease of cultivation. In Houaphan Province, *Eryngium foetidum* and *Nasturtium officinale* have long been cultivated, and *Limnophila chinensis* and *Houttuynia cordata* were grown since the 2000s. The main reasons for the recent practice of growing them were time saved in travel to distant harvesting sites, and demand for delicious and healthy vegetables. The domestication status and use of the seven Pan-Asian paddy field plants, namely *Centella asiatica*, *Oenanthe* spp., *Marsilea* spp., *Limnophila* spp., *Persicaria* spp., *Pontederia* spp., and *Houttuynia cordata*, were different among the focal regions in Asia. The results of this study suggest several drivers for switching from gathering wild paddy field plants to growing them: Lao dietary culture, which places a high value on wild foods, emerging demand for safe and healthy vegetables,

increase in the trade at local markets, and the plants' ecological traits of being easily propagated vegetatively and resistant to pests and diseases. In Lao PDR, cultivation of wild woody and climbing vegetables has recently been adopted as well. The results of this study will contribute to research on food security, conservation of economically important species, and plant domestication. The study of the ongoing dynamic relationships between people and plants has implications regarding the debate on the causal factors of domestication.

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Fig. 1. Location of the study sites in the Lao People's Democratic Republic (Lao PDR).

1: Chanthabuly District, 2: Xaythany District, and 3: Naxaythong District in Vientiane Municipality, 4: Thoulakhom District and 5: Phonhong District in Vientiane Province, 6: Xamneua District and 7: Houameuang District in Houaphan Province.

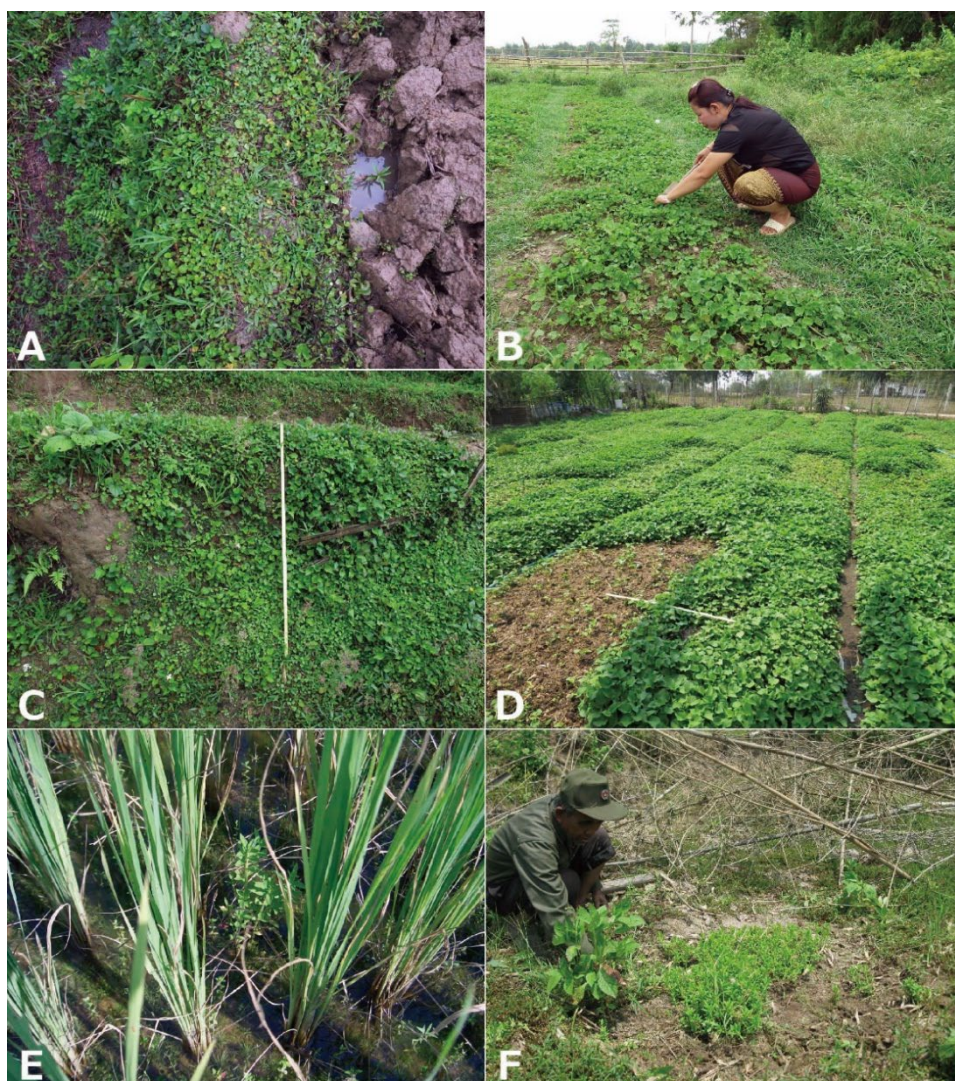


Fig. 2. Wild and planted paddy field plants in Vientiane Municipality/Province and Houaphan Province, the Lao People's Democratic Republic. A: *Centella asiatica* growing wild on a paddy field levee in Houaphan Province; B: *Centella asiatica* planted in a garden in Vientiane Province; C: *Houttuynia cordata* growing wild on the levee of a terraced paddy field in Houaphan Province. The white scale shows one meter in length; D: *Houttuynia cordata* planted in a garden with a sprinkler in Vientiane Municipality. The white scale shows one meter in length; E: *Limnophila geoffrayi* growing wild in a paddy field in Vientiane Municipality; F: *Limnophila chinensis* planted beside a paddy field in Houaphan Province. Bamboo cover was used to prevent livestock damage.

1 Table 1. Comparison of domestication status and use of seven Pan-Asian paddy field plants among the Lao People's Democratic Republic and other regions
2 in Asia.

	Vientiane, Lao PDR	Houaphan, Lao PDR	Mekong Delta, Vietnam ⁶	Yunnan, China ⁷	Kinki, Japan ⁸
<i>Centella asiatica</i> (L.) Urb. (Apiaceae)	Wild & Planted Vegetable	Wild Vegetable	Wild & Planted Vegetable	Wild Vegetable	Wild Not used
<i>Oenanthe</i> spp. ¹ (Apiaceae)	Not recorded Not used	Wild Vegetable	Wild & Planted Vegetable	Wild Vegetable	Wild & Planted Vegetable
<i>Marsilea</i> spp. ² (Marsileaceae)	Wild Vegetable	Wild Vegetable	Wild Vegetable	Wild Vegetable	Wild (Endangered) Not used
<i>Limnophila</i> spp. ³ (Plantaginaceae)	Wild & Planted Herb	Planted Herb	Wild & Planted Vegetable	Wild Vegetable	Wild Not used
<i>Persicaria</i> spp. ⁴ (Polygonaceae)	Wild & Planted Vegetable	Wild Vegetable	Planted Vegetable	Wild Vegetable	Wild & Planted Herb

<i>Pontederia</i> spp. ⁵	Wild	Wild	Wild	Wild	Wild (& Planted in
(Pontederiaceae)	Vegetable	Vegetable	Vegetable	Vegetable	the past)
					(Vegetable in the
					past)
<i>Houttuynia cordata</i>	Planted	Wild & Planted	Planted	Wild	Wild & Planted
Thunb.	Vegetable	Vegetable	Vegetable	Vegetable	Tea & Medicine
(Saururaceae)					

3 Note on species: 1. *Oenanthe javanica* DC. and *Oenanthe linearis* Wall.; 2. *Marsilea minuta* L. and *Marsilea quadrifolia* L.; 3. *Limnophila aromatica* (Lam.)
4 Merr., *Limnophila chinensis* (Osbeck) Merr., *Limnophila geoffrayi* Bonati, and *Limnophila rugosa* (Roth) Merr.; 4. *Persicaria barbata* (L.) Hara, *Persicaria*
5 *chinensis* (L.) H.Gross, *Persicaria hydropiper* (L.) Delarbre, *Persicaria odorata* (Lour.) Soják, and *Persicaria orientalis* (L.) Spach; 5. *Pontederia*
6 *korsakowii* (Regel & Maack) M.Pell. & C.N.Horn, *Pontederia hastata* L., and *Pontederia vaginalis* Burm.f..
7 Note on literature: 6. Ban and Duc (1994), Tanaka and Ke (2007); 7. Miyazaki (2016), Nishitani (2008), and Xu et al. (2004); 8. Ohashi et al. (2015–2017).

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- 12 Supplementary Data Table S1. Domestication and market status of paddy field plants used as vegetables in Vientiane Municipality/Province and Houaphan
 13 Province, the Lao People's Democratic Republic.

Species	Family	Local name ¹	Vientiane		Houaphan		Voucher number
			Domestication Status ²	Market Status ³	Domestication Status ²	Market Status ³	
<i>Alternanthera sessilis</i> (L.) DC.	Amaranthaceae	Phak kaan tan ຜັກການຕັນ			Wild	Home & Sale	Y.Kosaka 600 FOF
<i>Amaranthus viridis</i> L.	Amaranthaceae	Phak hom ຜັກຫົມ	Wild	Home & Sale			Y.Kosaka 150 FOF
<i>Centella asiatica</i> (L.) Urb.	Apiaceae	Phak nook ຜັກໜອກ	Wild & Planted	Home & Sale	Wild	Home & Sale	Y.Kosaka 100, 500 FOF
<i>Eryngium foetidum</i> L.	Apiaceae	Phak hoom pee ຜັກຫອມເປ	Wild & Planted	Home & Sale	Wild & Planted	Home & Sale	Y.Kosaka 125, 525 FOF
<i>Oenanthe linearis</i> Wall.	Apiaceae	Phak sii sang			Wild	Home &	Y.Kosaka 605

		ຜັກຊີຊ້າງ		Sale	FOF
<i>Hydrocotyle petelotii</i> Tardieu	Araliaceae	Phak neek	Wild	Home &	Y.Kosaka 610
		ຜັກແໜກ		Sale	FOF
<i>Crassocephalum crepidioides</i>	Asteraceae	Phak aa mang	Wild	Home &	Y.Kosaka 550
(Benth.) S.Moore		ຜັກອາມັງ		Sale	FOF
<i>Pseudognaphalium luteoalbum</i>	Asteraceae	Phak keep	Wild	Home &	Y.Kosaka 555
(L.) Hilliard & B.L.Burt		ຜັກແກບ		Sale	FOF
<i>Acmella oleracea</i> (L.)	Asteraceae	Phak khaat	Wild	Home &	Y.Kosaka 545
R.K.Jansen		ຜັກຄາດ		Sale	FOF
<i>Nasturtium officinale</i> R.Br.	Brassicaceae	Phak kaat nam	Wild &	Home &	Y.Kosaka 560
		ຜັກກາດນ້ຳ	Planted	Sale	FOF
<i>Lobelia nummularia</i> Lam.	Campanulaceae	Phak haak kouay	Wild	Home &	Y.Kosaka 585
		ຜັກຮາກກວຍ		Sale	FOF
<i>Stellaria aquatica</i> (L.) Scop.	Caryophyllaceae	Phak soop seep	Wild	Home &	Y.Kosaka 590

		ຜັກສອບແສບ			Sale	FOF
<i>Polycarpon tetraphyllum</i> (L.) L.	Caryophyllaceae	Phak dang som	Wild	Home		Y.Kosaka 615
		ຜັກດາງສົ້ມ				FOF
<i>Commelina diffusa</i> subsp.	Commelinaceae	Phak nya kaap			Home &	Y.Kosaka 575
<i>diffusa</i>		ຜັກຫຍ້າກາບ	Wild		Sale	FOF
<i>Cyanotis axillaris</i> (L.) D.Don ex	Commelinaceae	Phak lap thoot			Home &	Y.Kosaka 580
Sweet		ຜັກລັບຖອດ	Wild		Sale	FOF
<i>Astragalus sinicus</i> L.	Fabaceae	Phak seng			Home &	Y.Kosaka 620
		ຜັກແສງ	Wild		Sale	FOF
<i>Juncus prismatocarpus</i> R.Br.	Juncaceae	Phak phen			Home &	Y.Kosaka 570
		pheum	Wild		Sale	FOF
		ຜັກແພງເຜີ້ມ				
<i>Lindernia</i> sp.	Linderniaceae	Phak kan pou			Home &	Y.Kosaka 625
		ຜັກກ້ານປູ	Wild		Sale	FOF

<i>Marsilea minuta</i> L.	Marsileaceae	Phak ven	Wild	Home &		Y.Kosaka 105
		ຜັກແວ່ນ		Sale	FOF	
<i>Marsilea quadrifolia</i> L.	Marsileaceae	Phak ven		Wild	Home &	Y.Kosaka 505
		ຜັກແວ່ນ			Sale	FOF
<i>Glinus oppositifolius</i> Aug.DC.	Molluginaceae	Phak dang khom	Wild	Home &		Y.Kosaka 140
		ຜັກດາງຂົມ		Sale	FOF	
<i>Ludwigia hyssopifolia</i> (G.Don) Exell	Onagraceae	Phak bi ian	Wild	Home		Y.Kosaka 145
		ຜັກປີອ່ຽນ			FOF	
<i>Limnophila chinensis</i> (Osbeck) Merr.	Plantaginaceae	Phak kanyen nyai		Planted ⁴	Home &	Y.Kosaka 520
		ຜັກຂະແຍງໃຫຍ່			Sale	FOF
<i>Limnophila geoffrayi</i> Bonati	Plantaginaceae	Phak kanyen	Wild &	Home &		Y.Kosaka 120
		ຜັກຂະແຍງ	Planted	Sale		FOF
<i>Digitaria</i> sp.	Poaceae	Phak nya khouay		Wild	Home &	Y.Kosaka 540
		ຜັກຫຍ້າຄວາຍ			Sale	FOF

<i>Persicaria odorata</i> (Lour.) Soják	Polygonaceae	Phak pheo ຜັກແປວ	Wild & Planted	Home & Sale			Y.Kosaka 135 FOF
<i>Persicaria</i> sp.	Polygonaceae	Phak maimoo maimian ຜັກໃໝ່ໝໍ ໃໝ່ໝ້ງງ			Wild	Home & Sale	Y.Kosaka 535 FOF
<i>Pontederia hastata</i> L.	Pontederiaceae	Phak top ຜັກຕົບ	Wild	Home & Sale	Wild	Home & Sale	Y.Kosaka 115, 515 FOF
<i>Pontederia vaginalis</i> Burm.f.	Pontederiaceae	Phak nang hiin ຜັກນາງຮິນ	Wild	Home & Sale	Wild	Home & Sale	Y.Kosaka 110, 510 FOF
<i>Houttuynia cordata</i> Thunb.	Saururaceae	Phak khao thong ຜັກຂາວທອງ	Planted ⁵	Home & Sale	Wild & Planted	Home & Sale	Y.Kosaka 130, 530 FOF
<i>Viola</i> sp.	Violaceae	Phak khon houat ຜັກຂົນຫວດ			Wild	Home & Sale	Y.Kosaka 630 FOF

- 14 1 Only one local name was described although some plant species sometimes had several local names.
- 15 2 Domestication status: the species was growing in a wild habitat or planted in a garden.
- 16 3 Market status: the species was consumed at home or sold at local markets.
- 17 4 Transplanted from the northern region of Vientiane Province since the 2000s.
- 18 5 Transplanted from Houaphan, Xiengkhouang, and Xayabury Provinces since the 2000s.