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Does higher demand for medicinal plants lead to more harvest? Evidence from the dual trade of *Nardostachy jatamansi* and *Fritillaria cirrhosa* and Tibetan people's harvesting behavior

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Introduction: As the demand for herbal medicines is surging worldwide, regions of medicinal plants are vulnerable to large-scale and unsustainable exploitation for commercial trade and use. Yet, we still lack the understanding about the relationship between indigenous people harvesting and trade practices of medicinal plants and their influencing factors for possible intervention measures.

Methods: Here, we combined qualitative and quantitative methods to survey traders (N=20) and local harvesters (N=923) from nine Tibetan townships in Hongyuan county, Sichuan Province, on the eastern Qinghai-Tibetan plateau in China. Specifically, we elucidated the local value chain of medicinal plants trade and harvest of *Nardostachy jatamansi* and *Fritillaria cirrhosa*, and explored the factors influencing harvester's willingness to harvest these plants. Furthermore, we empirically tested the constructs of the COM-B model (Capability, Opportunity, Motivation -Behavior) in predicting the sustainable harvesting behavior of medicinal plants.

Results and Discussion: Our results revealed that the trade characteristics of *N. jatamansi* and *F. cirrhosa* were contrasting, and the sustainability of the former species was largely dependent on the latter one. Importantly, the traders' practices were affected by the supply, while the harvesters' willingness to harvest were mainly influenced by harvest incomes, past harvesting experience, and grassland tenure. Finally, though motivation was not directly affecting harvesting behavior, the harvesters' ecological worldview indirectly affected their harvesting behavior, particularly through the mediation of the level of compliance of village rules and customs. Overall, our results provided crucial insights for the conservation and sustainable management of the valuable wild medicinal plants.

KEYWORDS

traditional medicine, supply–demand, community-based management, COM-B system, Qinghai-Tibet Plateau

1. Introduction

As more and more people become health-conscious, the demand for herbal medicines surges worldwide, in part, owing to safer, cheaper, and lesser side-effects than mainstream allopathic medicines (Dhiman and Bhattacharya, 2020). Currently, most medicinal plants (MPs) are harvested from the wild, often unsustainably, and especially in the face of high market profit (Kling, 2016). Several examples of such unsustainable wild harvest have been highlighted in recent studies, such as those of *Ophiocordyceps sinensis* (Shrestha et al., 2014), *Fritillaria cirrhosa* (Cunningham et al., 2018b), and *Neopicrorhiza scrophulariiflora* (Ghimire et al., 2005). Most MPs are distributed in both biocultural diverse and economically underdeveloped areas, where commercial trade can ameliorate the livelihood of communities and develop the local economy (Olsen and Larsen, 2003; Shrestha and Bawa, 2014; Shrestha et al., 2019). Despite MPs receiving extensive attention in recent decades, particularly concerning its multiple roles in eradicating poverty and providing health care, the sustainability of the trade and use of MPs still faces enormous challenges owing to growing overexploitation (Astutik et al., 2019).

Unsustainable trade and use of wild MPs are considered as a major driver of ecosystem degradation and biodiversity loss (Shrestha and Bawa, 2013). Generally, local harvesting practice are influenced by market demand and price in regional and global markets (Weckerle et al., 2010), Surging prices can lead to unsustainable harvesting practice of many species, hence threatening their wild populations (Cunningham and Long, 2019). Current research on promoting the sustainable trade of wild resources has gradually shifted from the supply to the consumer demand side (Hinsley et al., 2015; Thomas-Walters et al., 2021). These findings shed light on the sustainable use management of wild resources through demand reduction. Nevertheless, sometimes the supply is not completely influenced by the market demand, and may also be affected by profit availability, past harvesting experience, and harvester household income and expenditure (He, 2018). Hence, it is crucial to elucidate the relationship between local commercial harvest and trade practices of MPs and their influencing factors to support the sustainable management of highly economic-valuable wild resources.

Commercial herbal medicine collection for trade is one of the most important productive lifestyles and sources of livelihood for Tibetan communities in the Qinghai-Tibet Plateau, where *N. jatamansi* and *F. cirrhosa* are widely distributed (from 2,500 to 5,000 m.a.s.l.) (Chauhan and Nautiyal, 2005; Cunningham et al., 2018b; Tali et al., 2019). *N. jatamansi* is a perennial herb of the Valerianaceae family, for which the rhizomes and roots are used as essential oil and traditional medicine owing to its antispasmodic and stimulant properties (Chauhan and Nautiyal, 2005; Dhiman and Bhattacharya, 2020). Unregulated harvesting and loss habitat have threatened the *N. jatamansi* wild populations in recent decades (Dhiman and Bhattacharya, 2020). As a result, *N. jatamansi* is listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1997 for better supervision of its international trade (CITES, 2000). While *N. jatamansi* was evaluated as Critically Endangered (CR) globally by IUCN, it was only classified as Least Concern (LC) by the Threatened Species List of China's Higher Plants in China (Ministry of Ecology and Environment of PRC, 2013; Chauhan, 2021). Although there has been some research on local use, trade contribution for livelihood, distribution, and cultivation of *N. jatamansi*, they are geographically focused on Nepal, the India and Pakistan (Airi et al., 2000; Chauhan and Nautiyal, 2005; Hamayun, 2007; Ali et al., 2012; Sahu et al., 2016). Nevertheless, in August 2021, *N. jatamansi* became listed at the "second conservation level" in the List of Wild Plants of National Priority Protection in China, which meant that collection permits are now needed for their harvesting.[1] Yet currently, we lack even a rudimentary understanding of the *N. jatamansi* domestic trade and harvest practice in China, where it also naturally occurs.

Different from *N. jatamansi*, China has one of the biggest demand markets for *Fritillaria cirrhosa* (Liliaceae) bulbs, which is used as a Traditional Chinese Medicine (TCM) (Cunningham et al., 2018b; Paudel et al., 2021). Despite increasing market demand, over-extraction of *F. cirrhosa*, and reports of decline in wild populations, the global conservation status of this species remains unevaluated by IUCN (Cunningham et al., 2018b; Mathela et al., 2021; Paudel et al., 2021). In comparison, *F. cirrhosa* is listed as a Near Threatened (NT) species by the Threatened Species List of China's Higher Plants in China (Ministry of Ecology and Environment of PRC, 2013). Additionally, as with *N. jatamansi*, *F. cirrhosa* has also been evaluated and listed at the "second conservation level" in the List of Wild Plants of National Priority Protection (see text footnote 1). However, unlike *N. jatamansi*, the international trade of *F. cirrhosa* has yet to be regulated by CITES. Therefore, it becomes vital to clarify the relationship between supply and demand of the regional trade, and to explore sustainable collection practices and conservation of the wild *F. cirrhosa* resources.

Current research on trade of wild medicinal plants has focused on some high-value medicinal plants, such as *Ophiocordyceps sinensis*, *Paris polyphylla*, *Neopicrorhiza scrophulariiflora*. The contents included illustrating the complexity of the domestic and international traditional Chinese medicine market (Ghimire et al., 2005; Shrestha et al., 2014; Cunningham et al., 2018a), although few studies have paid attention to the relationship between trade practices and harvesting behavior. Nevertheless, available studies found that the harvesters' willingness to harvest herb was more susceptible to market demand, and harvesters preferred to harvest plants that fetched a higher price (Shrestha et al., 2019). Although herb harvesting is an important source of household income, harvesters' willingness may be more likely to be affected by other non-economic factors, such as gender, past harvesting experience, and grassland tenure.

Thus, the contrasting domestic and international conservation statuses, and the competition of trade and use currently faced, *N. jatamansi* and *F. cirrhosa* might offer us an unique opportunity to explore the dynamic relationship between trade and use of two economically important medicinal plants whose distributional ranges overlap in a culturally unique region, where indigenous people's livelihood are largely dependent on the natural resources. Together, these factors highlighted the need to study the dual trade of *N. jatamansi* and *F. cirrhosa* and their sustainable use in China. We aimed to address three main research questions: (1) What are the domestic trade characteristics of *N. jatamansi* and *F. cirrhosa*? (2) Whether the trade demand of *N. jatamansi* and *F. cirrhosa* stimulate local Tibetan harvesters' harvesting practices? If so, what factors drive

1 http://www.forestry.gov.cn/main/3954/20210908/163949170374051.html

harvesters' willingness to harvest? and (3) How to promote the sustainable use of wild MPs resources? If the trade is driven by harvester, could we intervene the harvesting behavior of harvesters to promote sustainable management?

2. Theoretical framework and hypotheses

2.1. The COM-B model of behavior

The COM-B (i.e., the Capability, Opportunity, and Motivation to perform a Behavior) model proposes that the occurrence of a particular behavior requires a person's capability and opportunities to engage in that behavior, and motivation to carry it out more than any other behavior in the same context (Michie et al., 2011; West and Michie, 2020). In general, the more capable and with more opportunities favoring a behavior, the stronger the motivation, and the more likely an individual will perform that behavior (Michie et al., 2011; West and Michie, 2020). The COM-B system provides a theoretical framework to understand the mechanisms for predicting Tibetan harvesters' sustainable behavior (Figure 1A; Michie et al., 2011; West and Michie, 2020).

In the recent decade, the COM-B has been widely used to predict what needs to change for a behavior change intervention to be effective in various fields (Addo et al., 2018; Kropf et al., 2020; Irwin et al., 2022; Perros et al., 2022), with examples including public health care (Barker et al., 2016; West et al., 2020), water conservation (Addo et al., 2018), wildlife consumption (Thomas-Walters et al., 2021), clean energy promotion (Thompson et al., 2018; Perros et al., 2022), safety production (Irwin et al., 2022). Despite being a great potential to provide insights for the development of behavior change initiatives, the application of the COM-B to predicting sustainable behavior is only slowly taking shape, especially the harvesting behavior of wild medicinal plants. As an individual behavior with a decision-making process, the occurrence of sustainable harvesting behavior may also be influenced by different motivations, individual's physical or psychological capability and external opportunity. To test this idea, we created two hypotheses:

> *Hypothesis 1, 2*: Capability (H1) and opportunity (H2) would have a significant positive impact on harvester's harvesting behavior (Figure 1B).
>
> *Hypothesis 3, 4*: Capability (H3) and opportunity (H4) would have a significant positive impact on harvester's harvesting motivation (Figure 1B).
>
> *Hypothesis 5*: Harvesting motivation would affect Tibetan's harvesting behavior (Figure 1B).

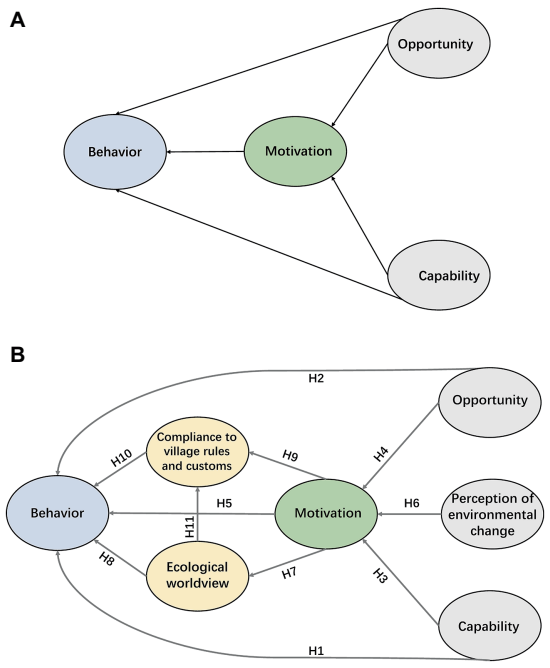

FIGURE 1
COM-B behavior systems **(A)** and research hypotheses **(B)**.

2.2. Perception of environment change

Many indigenous communities are among the most vulnerable to the impacts of environmental change (Salick and Ross, 2009; Ford et al., 2020). With livelihoods that are often highly dependent on the environment, the increased frequency and severity of environmental change can significantly affect indigenous communities (Pyhälä et al., 2016; Savo et al., 2016; van Gevelt et al., 2019). Much research has focused on studying risk perception, motivational factors and adaptive behavior (van Valkengoed and Steg, 2019; Wheeler et al., 2021), while the relationship between the perception of climate change, motivation and behavior have been understudied. Local perceptions of environmental change influence adaptation behavior, while the underlying motivations drive the specific behavior generally (Bockarjova and Steg, 2014; van Gevelt et al., 2019). The Tibetan plateau is already exhibiting some of the highest rates of climatic change in the world, local people have a unique way of perceiving changes to the climate and environment (Byg and Salick, 2009). We therefore proposed a hypothesis:

> *Hypothesis 6*: Tibetan harvester's perception of environmental change would affect their motivation to harvest MPs (Figure 1B).

2.3. Ecological worldview

The ecological worldview of Tibetan Buddhism of "no killing" and "sacred site worship" traditional belief, is beneficial to the protection of the natural environment (Luo et al., 2009; Yeh, 2014). Recent studies on the Tibetan people showed that religious belief had significant positive impact on community development and biodiversity conservation (Luo et al., 2009; Shen et al., 2012; Allendorf et al., 2014). As such, Tibetan culture likely shapes the social psychology, which is

unique to Tibetan's community, enabling them to meet various external challenges and to balance internal needs (Duojie, 2015). This makes Tibetans more likely to perceive and adapt to the changes of the environment, and to use natural resources more sustainably (Duojie, 2015).

> *Hypothesis 7*: Tibetans' motivation to harvest MPs would affect their harvesting behavior through their traditional ecological worldview (Figure 1B).
>
> *Hypothesis 8*: Tibetans' ecological worldview would directly affect their harvesting behavior (Figure 1B).

2.4. Compliance of village rules and customs

Local rules and customs are about respecting nature and local culture, but they have been used for resource conservation (Grumbine and Xu, 2011; Brinckmann et al., 2018). Religious and community leaders evaluate the beliefs of local community and then subsequently formulated them into customary law, which become applicable to local people's daily life in a specific community (Clarke and Jupiter, 2010; Lestawi and Bunga, 2020). So far, some of these works have tried to study their effects on the environmental governance and found the positive impact of the village rules and regulations on cleaner production behavior (Du et al., 2021). The Tibetan community governance is deeply influenced by Tibetan Buddhism and is framed in a unique community management mode (Luo et al., 2009; Yeh, 2014). Yet we still lack a rudimentary understanding of the process of how village rules and customs affect harvesting behavior at present. Hence, the following hypotheses are put forward:

> *Hypothesis 9*: Tibetan's motivation to harvest MPs would affect their harvesting behavior through their level of compliance of village rules and customs (Figure 1B).
>
> *Hypothesis 10*: The compliance of village rules and customs of Tibetan's harvesters would directly affect their harvesting behavior (Figure 1B).
>
> *Hypothesis 11*: Tibetan's ecological worldview would affect their harvesting behavior through their level of compliance of village rules and customs (Figure 1B).

3. Materials and methods

3.1. Study area

Our questionnaire survey was conducted across nine Tibetan communities located in Hongyuan County (32°48′N, 102°33′E), Sichuan Province, the east of the QTP, China, where the average elevation is about 3,000 m and the region is rich in biocultural diversity (Zhou, 2018; Figure 2). The Hongyuan meadow has a plateau continental climate that is characterized by a short and cool spring, summer, and autumn and a long winter (Wu et al., 2021). As of 2021, 87.7% of local population are Tibetans and are devout Tibetan Buddhists.[2] The grassland conditions of Hongyuan are much better than other Tibetan communities (Li, 2012). Here, most households are accustomed to grazing as their main form of livelihood, where their incomes are supplemented by harvesting herbs (Li, 2012) (see text footnote 2). Nevertheless, in recent years, some households have switched their livelihoods from traditional yak herding and grazing to operating a small provision shop or as temporary migrant workers (e.g., laborers).

3.2. Questionnaire design

We combined qualitative and quantitative methods to design the survey for traders and harvesters. We firstly reviewed relevant literature and identified the in-depth interview outline (Figure 3). We conducted a pilot in-depth interview across nine townships in Hongyuan County in March 2021. A total of 37 people was interviewed, who had ever harvested the medicinal plants, such as local harvesters, local Tibetan doctors, and temple monks. Our pilot interviews covered harvest behaviors, trade, livelihoods, policy, culture, and the environment. We recorded the interviews with the respondents' permission, then carried out open coding by Nvivo software. Finally, we used the grounded theory method to summarize the interview contents for the design of questionnaire (Pandit, 1996).

The semi-structured interviews with the local traders focused on understanding how their businesses operated and the prices they received for the *N. jatamansi* and *F. cirrhosa* (Table 1). Our final questionnaire for harvester has two major parts. The first one is about their family and household situation and demographics, which included the harvester's gender, family's financial situation (e.g., number of family-owned yaks, the yaks grazing area, the number of family expenditure categories), and Buddhism influence (i.e., the number of monks in the family) (Table 2). The second focused on using assessment scales to evaluate their self-reported harvesting behavior (a construct with nine statements), their capability (a construct with six statements), their opportunities (a construct with seven statements), their motivation (a construct with seven statements), their perception of environment change (a construct with eight statements), their ecological worldview (a construct with eight statements), and their compliance of village rules and custom (a construct with seven statements). We pilot tested the design on a sample of 134 local Tibetan respondents on November 2021. All scales used in the questionnaires have passed the reliability and validity tests in the pilot survey (Supplementary Table 1).

3.3. Data collection

Our primary data collection consisted of the trade section and harvesting section. In order to clarify the trade process and value

2 hongyuan.gov.cn

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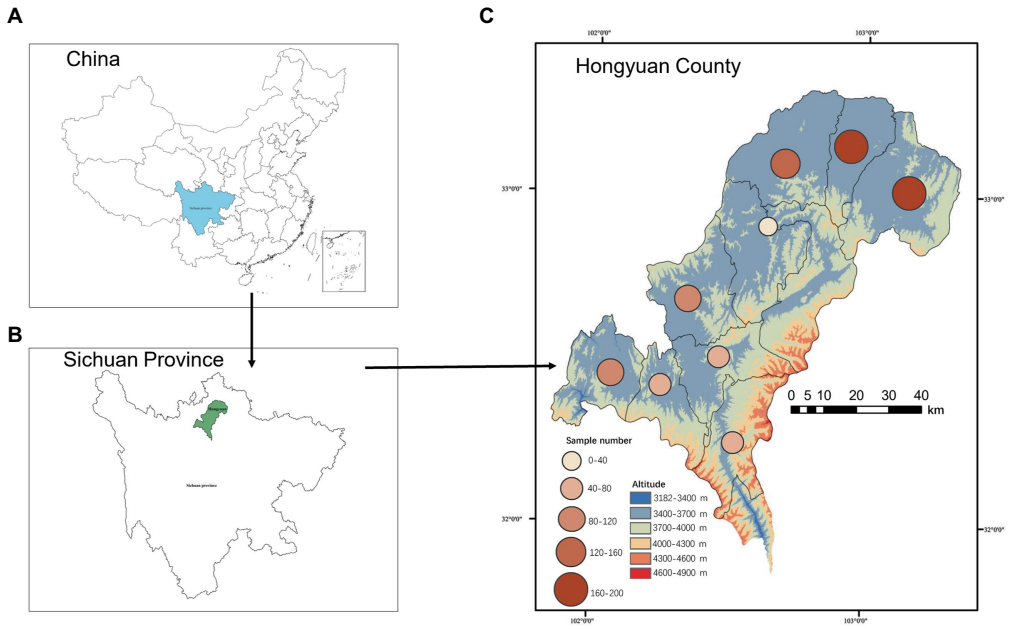

FIGURE 2
Location map of the study area. **(A,B)** Show the location of research area in the maps of China and Sichuan Province, respectively. **(C)** Shows the location of nine villages in the maps of Hongyuan County. For **(A)**, the blue area shows the location of Sichuan province in China. For **(B)**, the green area shows the location of Hongyuan County in Sichuan Province. For **(C)**, the size of the circle represents the number of interview samples.

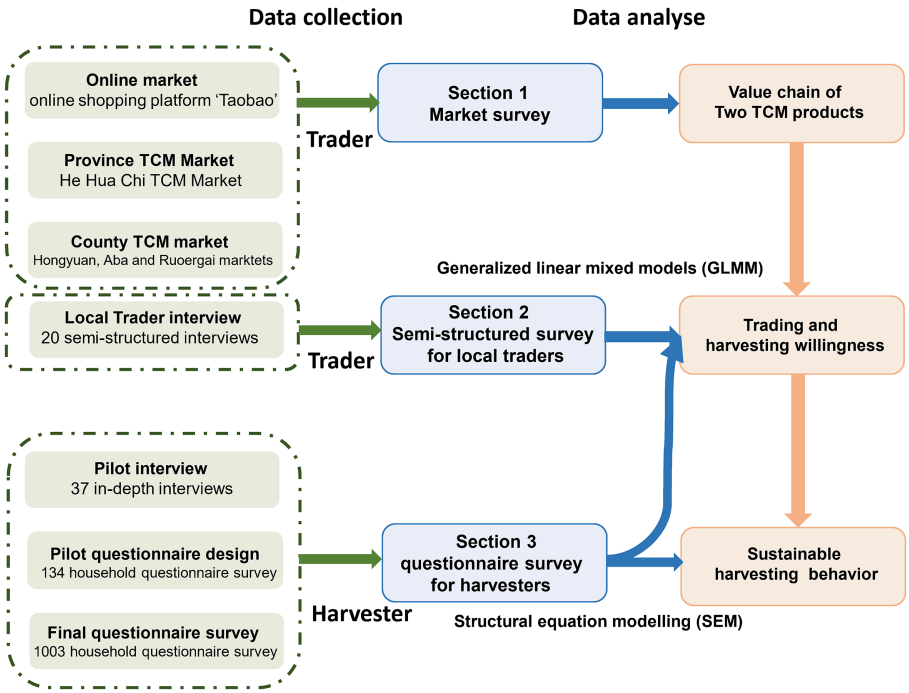

FIGURE 3
Flowchart of the research methodology.

chain of *N. jatamansi* and *F. cirrhosa*, our survey was conducted in three steps. First, we adopted a semi-structured interview for the local traders in June 2021. We interviewed the existing traders in Hongyuan County, where a total of 9 interviews were received. From these interviews, we were told that some township traders would sell their MPs to a MPs market in the nearby Aba County and a pharmaceutical factory in Ruoergai County. As such, we expanded our search and interviewed more traders in Aba County and Ruoergai County, ultimately accumulated a total of 20 possible interviews. Second, we visited a traditional medicine market in Chengdu to investigate the

TABLE 1 Sample characteristics of traders in Hongyuan county.

Variable	Variable type	Option	Total N	20%
Location	Categorical	Hongyuan	9	45%
		Aba	10	50%
		Ruoergai	1	5%
Ethnic	Categorical	Han	15	75%
		Tibetan	5	25%
Management pattern	Categorical	Family	16	80%
		Individual	4	20%
Trader hometown	Categorical	Sichuan province	17	85%
		Other provinces	3	15%
Full time	Categorical	Yes	6	30%
		No	14	70%
Trader age	Continuous	Cloze test	Mean	44.35
			S.D	13.16
Trading experience (year)	Continuous	Cloze test	Mean	9.94
			S.D	8.68

trade in *N. jatamansi* and *F. cirrhosa* (including gathering data on source areas, prices, levels of processing and product grading). Finally, through the online shopping platform "Taobao,"[3] we obtained records on July 2021 for raw materials products of *N. jatamansi* and *F. cirrhosa*, using Chinese keywords "甘松"and "穗甘松" (*N. jatamansi*), "川贝母" (*F. cirrhosa*) as the search term, to quantify their retail price and the number of participating retailers.

Furthermore, to interview the harvesters, we recruited nine local Tibetan undergraduate students, who are bilingual and proficient in Tibetan and Chinese languages, as research assistants to conduct offline face-to-face household questionnaire survey for local harvesters in January 2022. All questionnaires were filled out by the respondents, except those from the elderly respondents, who may be illiterate and needed assistance from the research assistants. A total of 1,003 questionnaires were initially received, with 923 deemed valid after excluding incomplete questionnaires. All responses to the questionnaires were entered manually into datasheets by the first author and second author for subsequent analysis. To check for and resolve errors during data transcription, we conducted sample extractions by sampling with replacement, to ensure all recorded content revealed no further errors (Supplementary Table 2).

Finally, this study received ethical approval from Ethics Committee of lead author's University (2022-0702-0255).

3.4. Data analysis

To better understand the harvesters' willingness to collect *N. jatamansi* and/or *F. cirrhosa* and the factors affecting their willingness, we selected a sample of 394 responses who indicated the presence of both *N. jatamansi* and *F. cirrhosa* in their family grassland. We then used generalized linear mixed models (GLMM) to analyze the factors of self-reported harvesting willingness of *N. jatamansi* and/or *F. cirrhosa*, including respondents' location (as a random effect variable), and their demographics. We identified their preference for harvesting *N. jatamansi* (model 1) or *F. cirrhosa* (model 2) as the response variable. The model 1 and model 2 selection process produced 33 and 40 top-ranked models ($\Delta AIC \leq 2$), respectively, which we averaged into the final model (Supplementary Tables 3, 4). Finally, we included other independent variables such as if the yaks were roaming freely, the number of yaks, the sale price of yak, the number of family members with junior high school education, their harvested income from *F. cirrhosa*, their harvested income from *N. jatamansi*, if they ever harvested *F. cirrhosa*, if they ever harvested *N. jatamansi*, the harvester's gender, the number of monks in the family, grassland tenure, and the number of family expenditure category in the final model (Supplementary Table 5). The GLMM analysis was performed using the lme4 R package in R 4.0.3 software.

Moreover, we used Structural Equation Modeling (SEM) to explore the influence of the constructs of the COM-B, such as the perceptions of environment change, the ecological worldview, and the compliance of village rules and customs on the sustainable harvesting behavior of MPs. We first used confirmatory factor analysis (CFA) to assess and identify the factors, which aimed to reproduce the observed relationships among a group of indicators with a smaller set of latent variables (Somers et al., 2003). We evaluated the construct validity through convergent and discriminant validity. Convergent validity includes factor loadings (FL) (recommended minimum value 0.6), composite reliability (CR) (recommended minimum value 0.6), and average variance extracted (AVE) (recommended minimum value 0.5) (Yi and Bagozzi, 1988; Chin et al., 1997). Based on convergent validity results, we determined the final observed variable items and re-estimated the measurement model (Supplementary Table 6). The goodness of fit indices shows an acceptable fit between the re-estimated model and the observed data (Supplementary Table 6). Next, a structural equation model (SEM) was used to evaluate the hypothetical path relationships among the latent variables (Tenenhaus, 2008). We constructed three SEMs ($N = 923$), where all variable relationships were estimated (i.e., Model 1), Model 1 excluding the harvesting motivation variable (i.e., Model 2), and Model 1 excluding the harvesting behavior variable (i.e., Model 3) (Supplementary Table 7). We used chi-square over degrees-of-freedom (X^2/df) (recommended maximum value 5), the Root-Mean-Square-Error of Approximation (RMSEA) (recommended maximum value 0.06) and the Standardized Root-Mean-Square Residual (SRMR) (recommended maximum value 0.1), the Tucker-Lewis Index (TLI) and the Comparative Fit Index (CFI) (all recommended minimum value 0.9) to assess model fits (Baumgartner and Homburg, 1996). Since the X^2/df value was greater than the recommended value, Model 3 ($X^2/df = 16$) was rejected, but Model 1 and Model 2 basically met the recommended threshold values. Although in general CFI and TLI values were slightly below the recommended value, a value of 0.8 is an accepted fit for a SEM model (Guerra and Giner-Sorolla, 2010; Supplementary Table 7). Compared to Model 2, the goodness-of-fit indices of Model 1 was more optimal, hence Model 1 was chosen as the final structural model. The CFA and SEM analyses were conducted using the Lavvan R package in R 4.0.3 software (Rosseel, 2012).

3 https://www.taobao.com/

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TABLE 2 Sample characteristics of harvesters in Hongyuan county.

Variable	Variable type	Option	Coding	Total N	923%
Location	Categorical	Amu	0	31	3.36
		Anqu	1	95	10.29
		Chaerma	2	94	10.18
		Jiangrong	3	78	8.45
		Longri	4	74	8.02
		Maiwa	5	183	19.83
		Sedi	6	176	19.07
		Rangkou	7	64	6.93
		Waqie	8	128	13.87
Harvester gender	Categorical	Male	0	366	39.65
		Female	1	557	60.35
Grassland tenure	Categorical	Family grassland	0	809	87.65
		Collective grassland	1	114	12.35
Yak roaming freely	Categorical	Yak cannot move freely	0	104	11.27
		Yak roaming freely	1	819	88.73
Number of yaks	Continuous	0	0	Mean	30.13
		Less 20	1	S.D	1.65
		21–30	2		
		31–40	3		
		More 40	4		
Yak price	Categorical	No change	0	248	26.87
		Increase	1	210	22.75
		Decrease	2	465	50.38
Number with junior high school education in family members	Continuous	0–2		Mean	0.66
				S.D	0.57
Number of family expenditure categories	Continuous	1–6		Mean	3.89
				S.D	0.57
Number of monks in the family	Continuous	0–2		Mean	0.39
				S.D	0.41
Have *F. cirrhosa* in family grassland	Categorical	No	0	327	35.43
		Yes	1	596	64.57
Have *N. jatamansi* in family grassland	Categorical	No	0	451	48.86
		Yes	1	472	51.13
Potential harvesting income of *F. cirrhosa*	Categorical	No	0	97	10.51
		Yes	1	826	89.49
Potential harvesting income of *N. jatamansi*	Categorical	No	0	497	53.85
		Yes	1	426	46.15
Past harvesting experience of *F. cirrhosa*	Categorical	No	0	99	10.73
		Yes	1	824	89.27
Past harvesting experience of *N. jatamansi*	Categorical	No	0	473	51.24
		Yes	1	450	48.75
Grading for sale	Categorical	No	0	670	72.59
		Yes	1	253	27.41

4. Results

4.1. Sample characteristics

In our study area, there is a larger proportion of Chinese Han traders than Tibetans involved in the business of MPSs (only 25% are Tibetan traders). Most of the trading were jointly run by couples (~80%), who were also running a provision shop in the village as their job (~70%). The traders were around 44 years old, while some had more than 10 years of trading experience (Table 1).

Respondents were sampled from 18 villages across nine towns in Hongyuan County (Table 2). Over 85% of harvesters reported that they usually harvested in their family grassland. Additionally, women were the main harvesters, where the proportion was around 60% (Table 2). Generally, all households were dependent on livestock-grazing as their main form of livelihood, possessing at least 30 yaks per household, though they felt that the yak prices were falling by the year (50.4%) (Table 2). More than half of the respondents felt that the grazing area was not large enough for their yaks, and around 11% of the respondents thought that the grassland was too small for yaks to graze freely (Table 2). Moreover, over 50% of the families reported that their family grasslands had *N. jatamansi* (51.1%) or *F. cirrhosa* (64.6%), and nearly 90% had harvested *F. cirrhosa* and obtained substantial income, while only 50% harvested *N. jatamansi*. Notably, more than 70% of the harvesters would choose not to sell even after the products were graded, since traders usually have some requirements for MPs quality (Table 2).

4.2. The trade of *Nardostachy jatamansi* and *Fritillaria cirrhosa*

The harvesting of *N. jatamansi* and *F. cirrhosa*, were entirely done by the local Tibetan harvesters, and nearly 80% of the interviewed locals had participated in harvest practices (Figure 4). Local wholesalers first pooled the *N. jatamansi* and *F. cirrhosa* from Tibetan's harvesters and sold them to Hehuachi TCM market (one of the largest TCM wholesale markets in China, located in Chengdu). Then the TCM could be further sold to pharmacies across the country, we noted more participants in the *F. cirrhosa* trade than the *N. jatamansi* trade in the transportation node of the value chain. Interestingly, the processes of cleaning and grading products were left to the county wholesalers, even though graded products could obtain higher profits. The average price of *N. jatamansi* paid to the harvesters is approximately 28–42 RMB/kg, and for *F. cirrhosa* it is up to 800–1,000 RMB/kg. For county trader, they could obtain over 60% profit from *F. cirrhosa* trade throughout the year, but that would mean more cash advance is needed. Generally, the harvesting of *N. jatamansi* begins in May, but most harvesters would halt the harvesting of *N. jatamansi* and choose to harvest *F. cirrhosa* between June and July, despite their grasslands having ample supply of *N. jatamansi* and high demand from the traders. After the relatively short period of *F. cirrhosa* harvest, the Tibetan's harvesters would go back to harvest *N. jatamansi* again until the first snow. In sum, the supply of *N. jatamansi* is dynamically dependent on the harvesting of *F. cirrhosa,* which is currently in shortage while *F. cirrhosa* appears to be in excess.

4.3. Trading and harvesting willingness of *Nardostachy jatamansi* and *Fritillaria cirrhosa*

For local trader, they preferred to collect *N. jatamansi* (67%) than *F. cirrhosa* (33%). Although they might get more profit from *F. cirrhosa* per kg, their annual income from the trade of *N. jatamansi* was far greater than that of *F. cirrhosa* (Figure 5B). Importantly, harvesters were more willing to collect *F. cirrhosa* (65%), even though more *N. jatamansi* supply was needed to meet the market demand (Figure 5A). We used GLMM to further explore whether the potential havesting income from either plant would directly affect the harvesters' willingness to harvest. Our results show that the potential harvesting income of *N. jatamansi* or *F. cirrhosa* and the past harvesting experience of such plants significantly and positively impacted the harvester's willingness to harvest the MPs (Figure 5C). This meant that harvesting income was not the only determinant of harvesting, and in some situations customs and experience mattered. Particularly, the Tibetan harvesters were more likely to harvest *F. cirrhosa* in their collective grassland over the family grassland, while the type of grassland tenure was not significant when it comes to *N. jatamansi*.

4.4. Determinants of the sustainable harvesting behavior

We built a SEM to test the hypotheses (Figure 1B) that affect the harvesting behaviors, Hypothesis 1–4, 6, 10, and 11 were proved, while Hypothesis 5, 7, 8, and 9 were not verified (Figure 6). Our SEM analyses show that both opportunity and capability had positive direct effect on the harvesting motivation of harvesters, and perception of environmental change also affected harvesting motivation directly ($p \leq 0.001$) (Figure 6 and Supplementary Figure 1). Additionally, the compliance of village rules and customs directly affected their behavior, whereas ecological worldview was not significant ($p \leq 0.001$). Interestingly, the sustainable harvesting behavior was not affected by harvesting motivation directly or indirectly. Through the mediation of their level of compliance to village rules and customs, Tibetan harvesters' ecological worldview may indirectly affect their harvesting behavior ($p \leq 0.001$). All the scales and constructs were significant at the 0.001 level.

5. Discussion

In China's TCM market, *N. jatamansi* and *F. cirrhosa* are completely different kinds of products, the former is common-bulk, while the latter is rare-precious. It is precisely due to the attributes of the commodities that may lead to varied trade venues and trade forms (Cunningham and Long, 2019). More Tibetan harvesters participated in the harvesting of *F. cirrhosa* over *N. jatamansi* (Figure 4). On the one hand, it may be directly determined by their own resources. Specifically, from the early 1990s, the grasslands, once held in collective, were divided into family-owned across China (Gongbuzeren et al., 2016). Some villages converted the remaining small area of grassland into village collective grassland, as in our study area. Indeed, over 50% of the locals reported that their family grassland had

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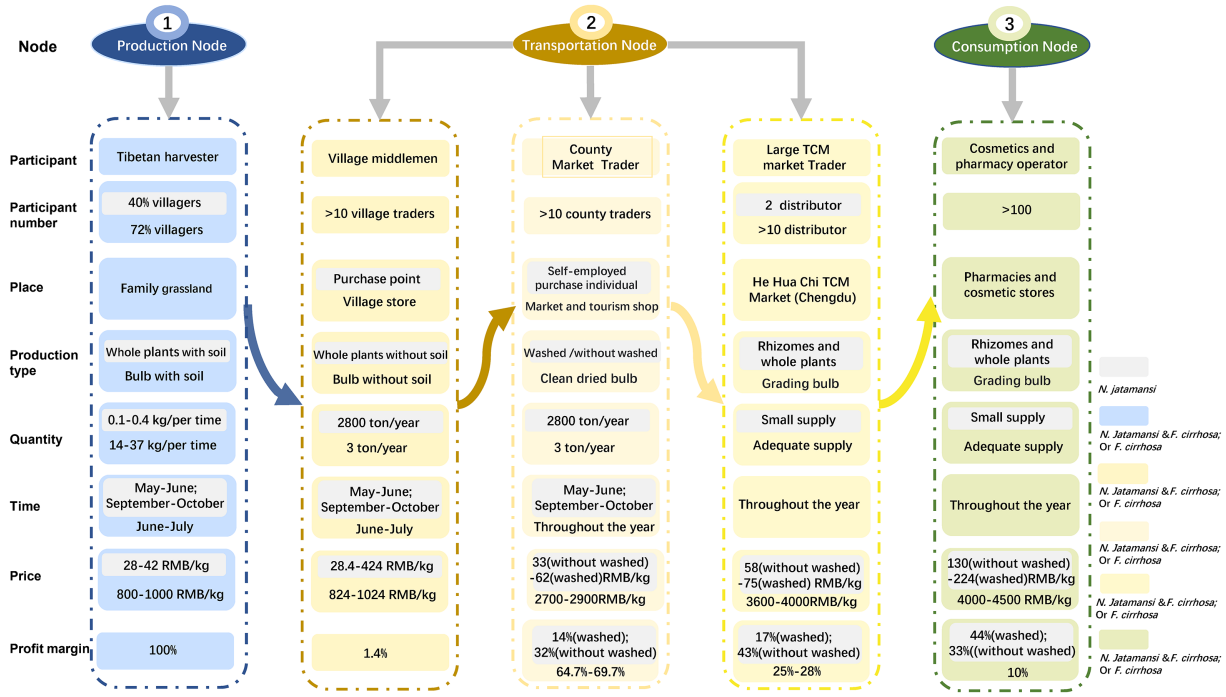

FIGURE 4
The trade and value chain of *N. jatamansi* and *F. cirrhosa*. The price is dry weight price; and the profit does not include labor cost and other material cost. Production node data is from the pilot interview (*N*=37) and harvester survey (*N*=923). The data of rural and county sections in transportation node are from trader interview (*N*=20) and investigation on Hehuachi TCM Market in Chengdu. Consumption node data is from online shopping platform "Taobao." Refer to the text (Result 4.2 the Trade of *N. jatamansi* and *F. cirrhosa*) for more details.

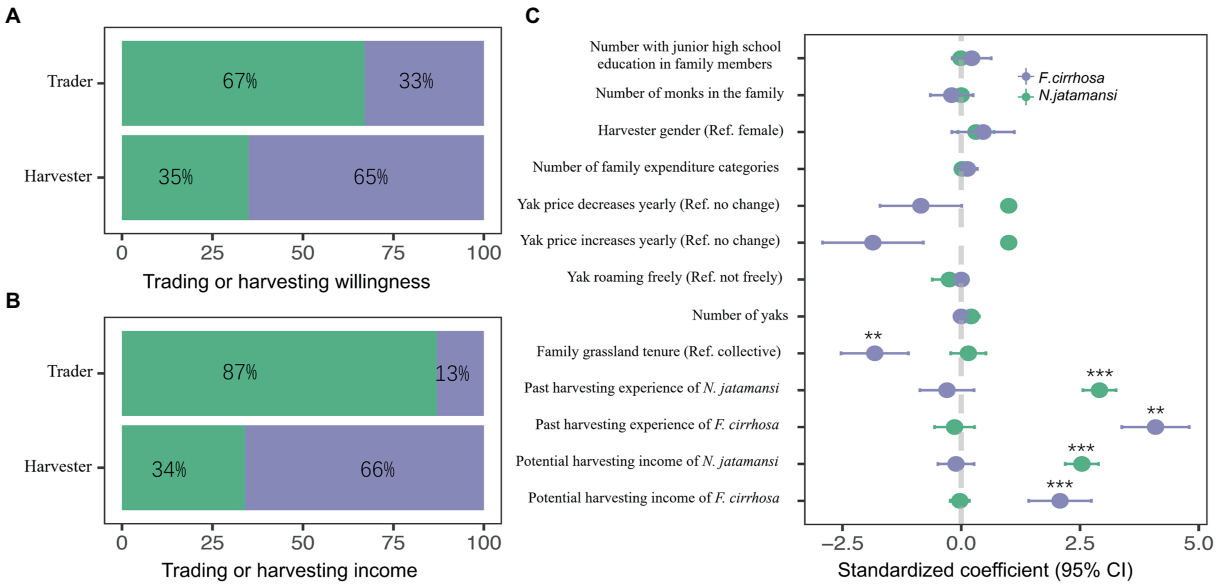

FIGURE 5
The proportion of harvester's (*N*=923) and trader's (*N*=20) willingness to harvesting and trading **(A)** and income **(B)** from harvesting or trading *N. jatamansi* or *F. cirrhosa*, and summary of GLMM estimate results and their standardized coefficients and 95% CI of harvesting willingness of *N. jatamansi* and *F. cirrhosa* (*N*=394) **(C)**. Purple color represents *F. cirrhosa*, green color represents *N. jatamansi*. Significance: ***$p \leq 0.001$; **$p \leq 0.01$.

F. cirrhosa, 10% more than *N. jatamansi* (Table 2). On the other hand, the harvesters are more inclined to pursue economically valuable products, which has been observed in *Ophiocordyceps sinensis*, *Paris polyphylla*, *Panax ginseng C. Meyer* (van der Voort and McGraw, 2006; Shrestha et al., 2014; Cunningham et al., 2018a). Moreover, in our study area, there is no other cost other than labor either in family

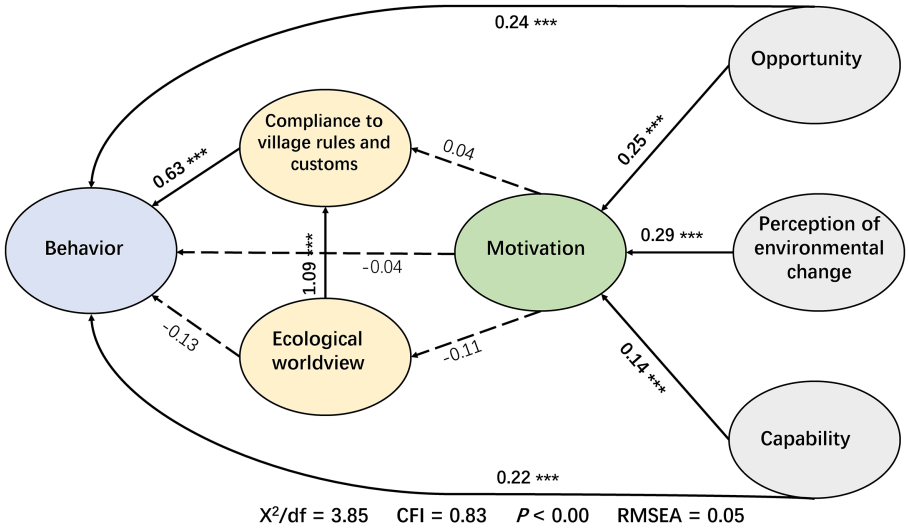

FIGURE 6
The summary of SEM results (Model 1) of the sustainable harvesting behavior (N=923). Path estimates are standardized coefficients. The solid line indicates significant correlation between variables, and the dotted line indicates not significant correlation between variables. Significant coefficient is marked in bold. ***$p \leq 0.001$.

grassland or collective grassland, which might directly lead to more people participating in the harvesting of *F. cirrhosa*.

Our research revealed that when the collection season of *N. jatamansi* and *F. cirrhosa* coincided, the Tibetan harvester would not hesitate to prioritize the harvest of *F. cirrhosa* (Figure 4). This suggest that when two herbs are harvested simultaneously, the market price of the product could be a key factor and might affect their harvesting priority (Joshi et al., 2006). As such, it is also likely that the sustainable trade of *N. jatamansi* would greatly depend on the trade practices of *F. cirrhosa* in Hongyuan County. Generally, research has traditionally suggested that the supply of TCM is influenced by market demand and price (Cunningham and Long, 2019; Hilonga et al., 2019), yet in our study we found that the harvesting practices of *N. jatamansi* and *F. cirrhosa* were not completely affected by the market demand (Figure 4). Although the local market demand of *F. cirrhosa* is not high, the price of *F. cirrhosa* has not decreased (Figure 4). This is because most traders would not lower the selling price of *F. cirrhosa*, often stockpiling it until the price is high again. Indeed, the imperishability of most TCM products gives traders and harvesters more influence in the market (He et al., 2018). However, for the township and county traders, it also meant their collection of *F. cirrhosa* require having considerable cash in advance (He et al., 2018).

Notably, whether it was *N. jatamansi* or *F. cirrhosa*, the harvesters' willingness was significantly affected by their past harvesting experience of each herb, except for the available income (Figure 5C). For one thing, the harvester would get more accustomed to harvesting familiar herbs, because they would master more knowledge about the harvesting practice, such as the distribution, harvesting method, and the harvesting time of the medicinal plants (Ghimire et al., 2004; Papageorgiou et al., 2020). For another, the pleasant experience and income feedback from the past harvesting experience would also encourage them to harvest such medicinal plant in the future (Shrestha and Bawa, 2014; Iponga et al., 2018; Yadav et al., 2019). Importantly, we found that locals significantly tended to harvest *F. cirrhosa* in collective grassland, even if there have *F. cirrhosa* in their family grassland (Figure 5C). Strategically, and understandably so, perhaps the locals are reserving the resources of their own grasslands since they have control, while prioritizing harvesting of collective resources for which are openly available to all. However, this is prone to the "tragedy of the commons," accelerating the depletion of regional resources, especially for perennial herbs with high market value such as *F. cirrhosa* (He, 2018). We therefore strongly suggest that resource protection and management should entail clear tenure system for high-economic plants harvesting to avoid a "tragedy of the commons" (Garrett, 1968; He, 2018).

Once the trade practice is heavily influenced by the harvesters at the beginning (i.e., supply) of the trade chain, their harvesting behavior become crucial to the sustainable use of wild resources (Shrestha and Bawa, 2013; Brinckmann et al., 2018). Some scholars claim that the motivation is an effective way to study how individuals behave, because motivation broadly involves evaluation mechanisms of behavior, for both reflective motivation and automatic motivation (Addo et al., 2018; Graham, 2020). Unfortunately, our results show that the harvesting motivation would not significantly affect their sustainable harvesting behavior among the Tibetan harvesters (Figure 6), the Hypothesis 5 had not been proved in this paper. It is not unusual that convenience, belief, and economics could perturb, modify, or sometimes even change sustainable harvest behavior of Tibetan's harvester, which may lead to the inconsistency seen between motivation and behavior (Boesi and Cardi, 2009; Bruschi et al., 2014; Kunwar et al., 2020). Because the gap of motivation-behavior was also commonly observed in other behaviors, future work should consider how to bridge this gap (Geng et al., 2017a,b).

The opportunities, abilities and the perception of environmental changes could significantly influence the harvesters' motives for harvesting practices, the Hypothesis 1–4 and Hypothesis 6 had been

tested (Figure 6). Opportunity could influence motivation as could capability. All the opportunity factors, including physical and social, which facilitate the occurrence of the motives (Michie et al., 2011). In our study area, the Tibetans' psychological and physical capacity to engage in the harvest activity may be the prerequisite for motivation. Moreover, some studies have reported that people who are engaged in climate-related occupations have a stronger perception of climate change, and that they are more likely to take adaptation measures to cope with climate change (Li et al., 2013; van Valkengoed and Steg, 2019). The measures may be related to the motivation of harvesting wild plants, especially when producing pro-environmental motivation. Indeed, Tibetan harvesters generally believe that harvesting practice of some root medicinal plants would have negative impact on the quality of the grassland. That is, when they perceive environmental changes strongly, they may likely to be more motivated for sustainable harvest to protect the grassland (Cencetti, 2011).

Interestingly, in our study, Tibetan's ecological worldview indirectly affected their harvesting motivation and behavior, *via* the mediation of compliance of village rules and customs. The Hypothesis 7 and Hypothesis 8 failed the test, while Hypothesis 11 passed the test (Figure 6). This suggests that sustainable harvesting practice may be promoted by strengthening ecological worldview and village rules, thereby promoting the sustainable use of wild medicinal resources. In China, religious Buddhism belief and ecological conservation are deeply rooted in local Tibetan people, in which they believe that life is equal and there should be no killing (Yeh, 2014). At the same time, the contents of most village rules and customs are integrated with their belief system in each Tibetan community, which are formulated by the village leadership team and the villagers through consultation (Cencetti, 2011; Brinckmann et al., 2018). From this perspective, it is apparent that the traditional ecological worldview would have a significant impact on the formulation of Tibetan village rules and customs (Figure 6). The compliance of village rules and customs would directly affected harvesting behavior, while not *via* the mediation of harvesting motivation. The Hypothesis 10 has been evidenced, and the Hypothesis 9 failed. As such, the restriction imposed by the village rules and customs likely plays an important role in the sustainable commercial and management of community resources, which has also been observed in our study (Weckerle et al., 2010; Brinckmann et al., 2018).

Overall, MPs are being used by indigenous people in Qinghai-Tibet Plateau areas owing to commercial and traditional use, it is therefore vital to build sustainability into the trade and harvest practice (Olsen, 2005; Sharma and Kala, 2018). Although the sustainable use behavior could be promoted through effective interventions, the sustainability of local market is still inseparable from effective regional management. Importantly, both *N. jatamansi* and *F. cirrhosa* are recently listed at the "second conservation level" of the List of Wild Plants of National Priority Protection in China, thereafter the collection of these two medicinal plants will require collection permits from relevant authorities (see text footnote 1). We therefore propose three recommendations to guide the management of economically important medicinal plants for local governments. First, the grading system of medicinal products has great potential to improve local benefit sharing and market sustainability (He et al., 2014; He, 2018). There is an urgency to provide training on the appropriate grading system to develop indigenous harvesters' understanding of price structures of differing quality products and grading techniques. Moreover, the species-specific harvesting techniques training for indigenous people are necessary, where it is helpful to avoid destructive harvesting practice and protect habitat (Sharma and Kala, 2018). If the harvesting of MPs influences the growth rate of wild species distribution, ecologically non-destructive methods of harvest practice should be employed, whereby rotational harvesting system could be introduced to promote the sustainable use of biodiversity, rather than imposing a ban on the harvest (Chauhan et al., 2013; Sharma and Kala, 2018). Lastly, local governments should also consider and adopt the certification scheme to manage harvesting practice. As seen elsewhere, this could perhaps contribute to community-based fair trade and maximize the income available to local community households (Brinckmann et al., 2018; Santika et al., 2021).

6. Conclusion

This study illustrates the importance of exploring the relationship between indigenous people's trade and harvesting practices of medicinal plants for sustainable use of wild resources, and the potential of COM-B behavior system to predict the sustainable harvesting behavior of medicinal plants. Our findings indicate that the trade sustainability of wild resources is not just dependent on the species in question, but likely that the other species are also involved and they are interdependent. And once the trade practice is heavily influenced by the harvesters, their harvesting behavior determines the extent of sustainable use of medicinal resources. Notably, in the Qinghai-Tibet Plateau, the harvesters' ecological worldview indirectly affected their harvesting behavior, particularly through the mediation of the level of compliance of village rules and customs. These findings provide crucial implications for developing policies of sustainable management and improving sustainable harvesting practices. First, regional trade management should be carried out for the overall management of all key species, due to their interdependencies, and should not only focused on endangered or/and high-value species. Besides, management policy of sustainable trade should also be directed at local harvesters who could possibly dominate trade activities, rather than focusing only on traders. Finally, efforts to promote the sustainable harvesting practice for harvesters through strengthening ecological worldview and village rules may be a feasible solution among the Tibetan communities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by JZ, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Department of Psychology, Sun

Yat-sen University (2022-0702-0255). The patients/participants provided their written informed consent to participate in this study.

Author contributions

JZ, TL, YZe, and YY came up with the initial idea. JZ and TL designed research and wrote the manuscript. JZ, SH, LF, and YZh performed research. JZ analyzed the data. All authors contributed to the editing of the manuscript and agreed upon the final version to be published.

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Conflict of interest

YZh was employed by the China Certification and Inspection Group Beijing Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1145928/full#supplementary-material

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