Uncovering caterpillar fungus (\textit{Ophiocordyceps sinensis}) consumption patterns and linking them to conservation interventions

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Abstract
Wildlife trade threatens global taxa. While interest in consumer behavior is increasing, such studies are scarce, particularly for plants and fungi, around questions of consumer characteristics, preferences, and perceptions. Moreover, these factors are not often marshaled to support conservation measures effectively. To address these questions, we examined the case of Chinese caterpillar fungus (\textit{Ophiocordyceps sinensis} [Berk.] G.H. Sung, J.M. Sung, Hywel-Jones, & Spatafora) consumers. This product is particularly interesting due to its extremely high value, economic importance to harvesters, and increasing conservation concerns. Data were generated through an online structured survey ($n = 1861$ consumers) and semi-structured qualitative interviews ($n = 65$) across six provinces that comprise the primary market in China. We found significant regional and demographic differences in consumer characteristics, preferences for the geographical origin of the product, and limited understanding of harvester and sustainability issues. Interestingly, consumers in higher income provinces bought less frequently but spent more money with the aim of self-consumption, compared with consumers in lower income provinces who buy more frequently, spending less, and with the intention to use purchased products as presents for family or friends. Consumer responses indicated that conservation measures can be enhanced through public information dissemination about product characteristics and linking consumers to the consequences of their consumption choices, with a particular focus on geographically differentiated information campaigns.

KEYWORDS
behavioral change, consumption, demand reduction, fungus trade, non-timber forest products, Traditional Chinese Medicine, wildlife trade, Yartsa gunbu
1 INTRODUCTION

Plants, fungi, and lichens are harvested throughout the world. More than 28,000 plant species are used for medicinal purposes (Willis, 2017), and environmental products contribute on average to 28% of total household incomes in tropical and subtropical countries (Angelsen et al., 2014). Species used to source commercial products are particularly prone to overexploitation, with negative conservation and livelihood impacts (Maxwell et al., 2016). For example, a recent study found that 117 of 300 commercially traded species in Nepal were classified into conservation categories (Pyakurel et al., 2019). Enhanced understanding of consumer characteristics and behaviors provides a demand-side approach to addressing overexploitation and illegal trade (Hinsley & 't Sas-Rolfes, 2020; Nuno et al., 2018; Phelps et al., 2013). This has been investigated in studies on rhino horns (Truong et al., 2015), pangolins (Wang et al., 2020), and sea turtles (Thomas-Walters et al., 2020). In general, investigations into the illegal wildlife trade are dominated by faunal studies; the booming trade in wild plants (Ticktin et al., 2020) and fungi (Frutos, 2020) remains understudied. While there is an increasing number of consumer-oriented plant (e.g., Hinsley et al., 2015; Williams et al., 2018) and fungi (e.g., Liang, 2011; Lu, 2017; Winkler, 2008; Yeh & Lama, 2013) studies, there is a lack of systematic large-scale quantitative investigations of consumer attributes.

This study investigates consumer characteristics, preferences, and perceptions for an extremely high-value environmental product. We focused on the Chinese market for Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones, & Spatafora, also known as the Chinese caterpillar fungus complex or Yartsa gunbu (“summer grass and winter worm” in Tibetan [“冬虫夏草” in Chinese], Figure 1). The traded complex comprises the larvae of one of 57 species of root-borers in the Hepialidae family infected and killed by the fungus’s ascospores (Wang & Yao, 2011). The stalked fruiting body is spotted by harvesters who dig up the larvae-fungus product (Zhang et al., 2012). The product is widely distributed in alpine grasslands on the Tibetan Plateau and the Himalayan mountains in India, Nepal, and Bhutan (Li et al., 2011, 2021), harvested by hundreds of thousands of households (Pouliot et al., 2018; Sulek, 2019) and comprises one of the most important sources of income for high-altitude communities (Sulek, 2019; Timmermann & Smith-Hall, 2019; Winkler, 2009). The product was previously used in local medicinal practices and Traditional Chinese Medicine (Cunningham & Long, 2019), and current demand is driven by the rapidly growing middle-class in China that

FIGURE 1  (a) The visible fruiting body, growing from (b) the head of the larvae, (c) the final air-dried product sold by harvesters in local markets, (d) example of high-altitude harvesting area, (e) digging only requires access and a hoe, and (f) an example of a packaged end product in a high-end store (photos by authors).
contributes the primary global market (He, 2018; Yeh & Lama, 2013). From 2002 to 2017, the retail price increased from around 3000 to 31,000 USD/kg (Cunningham & Long, 2019), with top-quality specimens reaching 145,000 USD/kg (Li et al., 2021), likely making *O. sinensis* the most valuable renewable environmental product in the world, with an annual trade value worth billions of USD (Shrestha, 2012). Total annual harvests have been estimated at 85–185 tons (Winkler, 2009).

Research suggests overexploitation of *O. sinensis* throughout the distribution range, based on harvester perceptions, typically of decreasing numbers of specimens that can be collected per time unit (e.g., Hopping et al., 2018). However, there is a lack of hard data on causal linkages and thus competing alternative explanations, for example, a decrease in specimens per time unit may be due to fewer specimens and/or more harvesters (Smith-Hall & Bennike, 2022). Assessing the sustainability of *O. sinensis* harvesting is challenging due to the complex ecology surrounding the involved species (moth and fungus) and their interactions with the surroundings, including changing habitats and climate (Hopping et al., 2018). Key factors influencing *O. sinensis* production remain unidentified. *O. sinensis* was recently listed as vulnerable on the IUCN Red List due to “its strict host-specificity on moth insects, and confined geographical distribution, and over exploitation by humans in recent decades” (Yang, 2020, p. 1). Demand drivers remain poorly understood, with most studies referring to anecdotal evidence of the product's use as an aphrodisiac in China. Yeh and Lama (2013) provided insight into *O. sinensis* gift-giving in China, but it remains uncertain whether this is a dominant driver of demand in terms of volume. Here, we present a structured investigation of *O. sinensis* (i) consumer characteristics, preferences, and perceptions; and (ii) how these can support interventions to bolster conservation efforts. We expand the caterpillar fungus complex literature to include large-scale consumer surveys. Our findings from the main Chinese market enable us to make recommendations to address rising concerns about unsustainable trade in wild-harvested, extremely high-value renewable environmental products.

## 2 METHODS

Data collection was carried out from May to December 2018 in two sets of contrasting provinces/municipalities: Beijing, Shanghai, and Guangdong (in Eastern China), representing high-income and developed provinces/municipalities; and Yunnan, Sichuan, and Chongqing (in Central and Western China) representing closer-to-resource and developing provinces/municipalities. Assuming that *O. sinensis* consumption is widespread in China, this contrast allowed higher variation in consumer characteristics (such as income and education) and thus more variation in preferences and perceptions.

We employed an online structured caterpillar fungus consumer survey (Appendix S1) and offline semi-structured interviews with consumers and officials. The online 10-min survey was implemented using the “SurveyStar” platform [https://www.wjx.cn] and covered (i) demographic information; (ii) buying behavior; (iii) consumption behavior; and (iv) perceptions of sustainable use. The questionnaire was based on the authors’ long-term engagement in *O. sinensis* research and informed by existing literature, including Yeh and Lama (2013), He et al. (2018), Pouliot et al. (2018), and Cunningham and Long (2019). An online pre-testing of the survey was performed with six persons of different ages, gender, and education levels. Adopting multi-stage stratification random sampling (Coleman, 1958), the respondents were recruited via the survey platform, which has over 2.5 million registered participants. For each province/municipality, approximately 320 respondents were randomly recruited in a list of registered participants in “SurveyStar” across three age groups (20–29 years, 30–40 years, and over 40 years). We recruited 1959 participants; using a scanning question to exclude those who had never purchased caterpillar fungus, as well as those responding too fast (in under 2 min) or too slow (over 50 min), as suggested by Wright (2005), a 95% completion rate resulted in a sample of 1861 respondents. Each participant completing the survey was compensated with 12 RMB (about 2 USD). Qualitative data were derived from in-depth interviews with 10 consumers in each province/municipality using snowball sampling, with the initial informants selected using the authors’ varied personal connections. Also, five key informants, officials at the National Forestry and Rangeland Management Administration and experts in fungi, were interviewed. Consumer interviews covered levels of understanding of the medicinal functions of *O. sinensis*, the reasons for purchasing the product, and their perspective on local livelihoods and sustainable use. Interviews with officials focused on current government regulations on *O. sinensis* management, harvesting, trade, and sustainable use.

Quantitative data were analyzed using descriptive statistics, OLS regression and logistical regression analysis in STATA 13 to test for significant differences in consumption behavior (e.g., across regions, age groups, and education). Qualitative data were recorded, transcribed, and subjected to content and thematic analyses to uncover consumption patterns, governance in trade and management, and sustainable uses. Qualitative data were
Further used to inform the interpretation of quantitative data. This combination of quantitative and qualitative approaches generated a robust range of data analyses, helping to understand better the current consumption of caterpillar fungus and the potential for sustainable use.

3 | RESULTS

An overview of the structured survey respondents (n = 1861) is presented in Table S1 (Appendix S2); 54% were female, and most were highly educated, with nearly 71% possessing a bachelor’s degree or higher. The largest three groups of occupations were professionals (26%), officials (21%), and people working in business and service sectors (18%). Annual incomes ranged from <4600 USD to more than 76,000 USD in a normal distribution.

3.1 | Consumer characteristics—Who purchased caterpillar fungus and why?

O. sinensis is an expensive product, and most people purchased it infrequently, with more than 64% of the respondents buying it less than once a year (Figure 2a), but with province-level variation—46% of respondents in Guangdong province bought caterpillar fungus at least once a year, with around 28% buying it three or more times a year. A similar pattern and variation type are found at
the level of annual expenditure (2B). Respondents in developed provinces/municipalities or at high-income levels spent significantly more money annually \((p < .001, SE = 0.097\) for province, \(p < .001, SE = 0.039\) for income level, Table S2) but bought significantly less frequently \((p < .001, SE = 0.06\) for province, \(p < .01, SE = 0.024\) for income level, Table S3). Male customers were more likely to purchase higher amounts of caterpillar fungus \((p < .001, SE = 0.094, Table S2)—approximately 16% spent about 1500 USD annually, and 17% purchased it more than three times annually. The 30–40 year age range comprised the customers who bought most frequently and made the most expensive purchases.

The people who buy the caterpillar fungus may not self-consume it: more than 40% of respondents purchased with the intent of gifting others the caterpillar fungus (Figure 2c). In the qualitative interviews, people stated that caterpillar fungus is a good gift for friends, family members, and work-related seniors and leaders, as it has widely recognized medicinal and economic values. Interestingly, there was spatial variation in gift-giving, with respondents in developed provinces less likely to buy caterpillar fungus as a gift \((p < .05, SE = 0.094, Table S2)—approximately 16% spent about 1500 USD annually, and 17% purchased it more than three times annually. The 30–40 year age range comprised the customers who bought most frequently and made the most expensive purchases.

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### 3.2 Consumer preferences

Most consumers (58%, Figure 3a) preferred purchasing caterpillar fungus from pharmacies; online and souvenir shops only account for around 4% and 3%, respectively. Consumer interviews revealed that pharmacies were viewed as more trustworthy, with a lower chance of receiving a fake product. Consumers had clear preferences of origin, perceiving the highest quality to come from Tibet (52%), Yunnan (24%), Qinghai (13%), Sichuan (6%), Nepal (2%), Bhutan (1%), and India (0.2%) (Figure 3b).\(^2\) Yunnan was picked over Qinghai as a place for better quality caterpillar fungus as it is a popular tourism destination, making caterpillar fungus a well-known local specialty, as indicated in the qualitative interviews. The price is an influential factor of consideration when
purchasing (67%), followed by origin (56%), freshness (54%), smell, color, and size (Figure S1A,B).

People consumed caterpillar fungus as they believed (Figure 3c) the product to boost the body (58%, e.g., enhanced energy or improving the immune system), control diseases (49%), improve blood circulation (42%), enhance sexual potency (22%), or cure cancer (18%). A number of people consumed it believing it had unknown positive effects (22%). Consumption is also characterized by varying ingestion pathways (Figure 3d), ranging from people advocating for cooking with chicken and meat (32%), consuming it with water (13%), liquor (10%), cooked in water (8%), powdered (8%), or taken with another drug (5%). A substantial number of respondents did not know the best way to consume the product (22%). Secondary processing of the caterpillar fungus into pill form was the least-preferred way to consume the product (2%). The qualitative interviews indicated that people do not know any scientifically proven best way of preparing the caterpillar fungus, with most resorting to following common practices, including cooking with chicken and meat or steeping in liquor.

3.3 Consumer perceptions

Respondents expressed concern about the impact of the caterpillar fungus trade on sustainable harvesting: 56% perceived an impact on the resource, 15% that there was no impact, while 30% did not know (Figure 3e). Officials and higher-income respondents differed significantly in perceiving a higher impact of trade on sustainability ($p < .01$, SE = 0.109 for officials, $p < .01$, SE = 0.041 for income level, Table S5). There was also a significant difference between provinces, while respondents in developed provinces more concerned about the impact of harvests on sustainability ($p < .001$, SE = 0.101). Respondents who purchased more frequently tended to be more concerned about the sustainability of the trade ($p < .001$, SE = 0.041, Table S5). Perceived strategies to improve sustainability (Figure S1C) focused on regulating harvest practices (60%), improving harvest techniques (55%), legislative regulation of harvest (50%), certification (47%), and capacity building for harvesters (43%). Harvesters’ self-governance was given the lowest priority (30%). Regarding the latter, the qualitative interviews indicated that most respondents believed that harvesters would maximize income and hence be unable to achieve sustainability through self-governance.

Many respondents (45%, Figure 3f) found that commercial harvest and trade did not provide long-term benefits for local harvesters, while 39% were “not sure.” The interviews revealed that some people believed unequal benefits across the value chain can undermine harvesters’ benefits; the interviews also showed limited awareness of relationships between ecological and economic sustainability. Perceived strategies to improve benefits for harvesters (Figure S1D) included improved caterpillar fungus resource management (58%), certification of green food (52%), certification of fair-trade (49%), training for harvesters (49%), branding (45%), and improved e-commerce (41%). Establishing farmer cooperatives was given the lowest priority.

4 DISCUSSION AND CONCLUSION

This study elucidates caterpillar fungus consumer characteristics, preferences, and perceptions. How can these empirical findings from China, the main consumption country, be used to support the development of practical conservation and policy interventions? Three recommendations stand out.

First, there are regional and demographic differences in consumer characteristics, preferences, and perceptions. High-income consumers in developed regions spent more money purchasing $O. sinensis$; a similar pattern was found for wild-harvested orchids in China (Williams et al., 2018). Guangdong appears particularly important in connection to plant, fungi, and faunal consumption for medicinal purposes (Chen et al., 2019; Williams et al., 2018). In developing regions, people spent less money and purchased the caterpillar fungus more frequently as a gift for others, with officials comprising a significantly higher proportion of buyers. This supports earlier findings on the importance of $O. sinensis$ in gift-giving as part of establishing social networks and paying bribes (Cunningham & Long, 2019; Yeh & Lama, 2013). Intertwined with caterpillar fungus consumption is the notion that the product should come from unpolluted landscapes, purified by their distance from human settlements and capable of delivering myriad health benefits (Liang, 2018). These cultural perceptions embedded in the product contribute to explaining the rapidly increasing prices (Cunningham & Long, 2019; He, 2018; Woodhouse et al., 2014). This indicates that artificial propagation and other substitutions for the wild-harvested product might not be effective demand reduction measures, as suggested by Liu et al. (2015). Instead, geographically differentiated information campaigns targeting specific selling points could reach key consumers with tailored messages.
Second, consumer understanding of biophysical aspects of caterpillar fungus harvest, trade, and use is limited. This includes limited insights into origins (with Qinghai being a dominant source area but with a distribution range including the Tibetan Plateau and the Himalayan range; Li et al., 2011; Wei et al., 2021) and issues related to trade sustainability, including a lack of understanding of the potential role of local people and communities in establishing and controlling sustainable use. Regarding use, research has shown that bioactive molecules in O. sinensis can prevent and treat diseases by increasing both the cellular ATP levels and oxygen utilization by muscles, with anticancer properties (De Silva et al., 2012; Paterson, 2008). Nevertheless, much consumer usage is still centered around undocumented functions, including enhanced sexual potency (Lo et al., 2013; Martel et al., 2017) and is characterized by a lack of knowledge on required volume and methods of ingestion. This indicates that rising demand and prices are partially driven by consumer misperceptions of product efficacy, as also observed for many traditional Chinese medicines (Chee, 2021; Zhan, 2001). Demand reduction could thus be facilitated via disseminated public information about product characteristics.

Third, consumers paid limited attention to potential sustainability issues, including their personal contribution through their purchases. This, again, indicates a potential to influence demand through publicizing relevant information. However, as demand reduction would have severe economic implications in rural producer communities (He, 2018; Pouliot et al., 2018; Sulek, 2019; Timmermann & Smith-Hall, 2019; Winkler, 2009), such interventions should be based on data-informed sustainability studies. The current understanding of the sustainability of O. sinensis commercial harvesting remains limited (Smith-Hall & Bennike, 2022). Studies have addressed issues related to harvesting and technology (He, 2018; Weckerle et al., 2010), climate change (Hopping et al., 2018; Wei et al., 2021), and markets (He et al., 2018; Pouliot et al., 2018), but no studies provide data to document overexploitation in a particular location—this is limited to proxies (such as decreasing number of specimens that can be collected per day) that may have several explanatory factors. Crucially, we still do not know what part of the complex caterpillar production cycle is the main limiting factor. Assuming current unsustainable harvest levels, both producers and consumers would have an interest in securing future supplies. As in other cases of wild-harvested demand-driven trade (He, 2018; Truong et al., 2015), sustainability interventions can be pursued throughout the value chain, including in relation to benefit-sharing (Shrestha & Bawa, 2014; Yeh & Lama, 2013) and linking consumers to the consequences of their consumption choices.

**AUTHOR CONTRIBUTIONS**

Jun He: Methodology, Conceptualization, Investigation, Formal analysis, Funding acquisition, Writing - original draft, Writing - review & editing, Project administration, Supervision. Carsten Smith-Hall: Methodology, Conceptualization, Formal analysis, Funding acquisition, Writing - original draft, Supervision. Wen Zhou: Methodology, Data curation, Formal analysis, Writing - original draft. Weijia Zhou: Methodology, Data curation, Formal analysis, Writing - original draft. Yunshang Wang: Investigation, Writing - review & editing. Ben Fan: Investigation, Writing - review & editing.

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**CONFLICT OF INTEREST**

The authors declare no conflicts of interest.

**DATA AVAILABILITY STATEMENT**

The data that support the findings of this study are available from the corresponding author upon request.

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**ENDNOTES**

1 In the qualitative interviews, we found a reduced tendency over time to purchase caterpillar fungus as a gift, as also observed by Cunningham and Long (2019) who reported a dramatic caterpillar fungus price decrease as a result of the anti-corruption campaigns of President Xi Jinping.

2 The survey was not broken down below the level of province (prefectural or county levels) in China, as there is little evidence, in either the literature or the authors’ experiences, that consumers have any such detailed perceptions of origin.

3 “Green food” refers to food produced and processed under the principles of sustainable development and certified by the China Green Food Development Center under the Ministry of Agriculture (see Sanders, 2006).
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**SUPPORTING INFORMATION**

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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