A systematic survey of online trade in the caterpillar fungus *Ophiocordyceps sinensis*

Reshu Bashyal*[1] and David L. Roberts[2]

Abstract Although wildlife trade has received considerable research and conservation attention, much of it has been focused on charismatic species, with taxa such as fungi receiving little or no attention despite being highly sought after. The caterpillar fungus *Ophiocordyceps sinensis* is highly valued as an ingredient in cosmetics and medicines, and as an aphrodisiac and dietary supplement. Despite its livelihood and socio-economic significance, it has received little attention in either research or wildlife trade policy. Nevertheless, trade appears to be rampant, and growing online, and this is an emerging conservation challenge. Here we present a systematic survey of online trade in the caterpillar fungus during 2021. During this period, 168 advertisements were recorded on eight e-commerce platforms, both national and international. The grade of the caterpillar fungus advertised for sale fell into six categories. Fungi described as pure/organic/wild grade, which we categorized as authentic grade, had the highest median price (24 USD/g) and those described as medicine/food/cosmetic/beverage, which we categorized as consumption grade, had the lowest median price (0.04 USD/g). The highest advertised sale price was for caterpillar fungus of Bhutan origin (155 USD/g) advertised on the eBay e-commerce platform. Trade in caterpillar fungus on national and international online platforms is evident, and trade in other non-charismatic species is also likely burgeoning online but remains poorly documented. Further systematic surveys of online trade are required, not only to improve understanding of such trade but also to facilitate the development of effective conservation interventions and prevent undocumented overexploitation of important natural resources in developing countries.

Keywords Caterpillar fungus, e-commerce platform, fungi, Himalaya, online trade, *Ophiocordyceps sinensis*, wildlife trade, yarsagumba

Introduction

Much of the attention given to the wildlife trade has been focused on the commercialization of a small selection of wild animals, particularly charismatic large mammals (Fukushima et al., 2020). Although some high-value plants are beginning to receive significant attention (e.g. ebony *Diospyros ebenum*, rosewood *Dalbergia latifolia*, and other timber species; UNODC, 2016; Whitehead et al., 2021), the issue of plant blindness (Phelps & Webb, 2015; Margulies et al., 2019) remains. Fungi have received little or no attention in research and conservation policies (Oyanedel et al., 2022).

The caterpillar fungus *Ophiocordyceps sinensis* is traded globally (Shrestha & Bawa, 2015; Stone, 2015), but little is known regarding its trade as a wildlife commodity. The major reason for its trade is its use in medicinal traditions such as Ayurveda, Chinese and Nepali folk medicines (Devkota, 1970; Adhikari, 2009; Shrestha & Bawa, 2013). It is also used in cosmetics, as a dietary supplement (Belwal et al., 2019) and as an aphrodisiac (Holliday & Cleaver, 2008; Winkler, 2009; Thapa et al., 2014). Demand is largely from China, where it is marketed to treat ailments under traditional Chinese medicine (Thapa et al., 2014). This high demand has caused a dramatic increase in its market price, outstripping many other wildlife commodities. The increase in price in some countries, such as Nepal, has been as high as 2,000% in 10 years (Stone, 2015).

The habitat of the caterpillar fungus is the remote alpine and subalpine pastures of Bhutan, India, Nepal and China (Yadav et al., 2019). The increased demand and price in global markets make it an important income source for rural communities (Pant et al., 2017). In some rural communities of the Himalayas, the species acts as a financial safety net (Shrestha & Bawa, 2014; Yadav et al., 2019; Karki et al., 2020), providing 50–70% of household income (Wang et al., 2022) whilst also reducing income inequality by as much as 38% (Shrestha et al., 2019). Furthermore, it is one of the most important contributors to household economy amongst the > 60 non-timber forest products (NTFPs) that are harvested in the Himalayas (Shrestha & Bawa, 2014). In the Nepal Himalayas, various NTFPs, including plants and fungi, are traditionally harvested and contribute up to 90% of the income of poor households (Bista & Webb, 2006).

Despite its socio-economic significance, there is limited knowledge of the caterpillar fungus trade, with much of what is known being based on interactions with local harvesters and key stakeholders (Shrestha & Bawa, 2013; Thapa et al., 2014; Hopping et al., 2018; Shrestha et al., 2019; Yadav et al., 2019) and analysis of available production data (Winkler, 2009; Wang et al., 2022). Although this information could provide site-specific trade information,

*Corresponding author, bashyalreshu@gmail.com
[1]Greenhood Nepal, Kathmandu, Nepal
[2]Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, Marlowe Building, University of Kent, Canterbury, UK

Received 17 September 2022. Revision requested 1 March 2023.
Accepted 21 August 2023. First published online 10 January 2024.

overall trade statistics are poorly known and there has been little attention to the development of conservation strategies or policy for this trade. This is partly because most attention is given to selected wild animals and little to plants and fungi, a matter often referred to as plant and fungal blindness (Margulies et al., 2019; Fukushima et al., 2020), as highlighted in studies appealing for policy action (Goncalves et al., 2021; Oyanedel et al., 2022).

Currently, there are no fungi listed in the CITES Appendices. Although this could be because they do not meet the criteria for listing, it is more likely because of a lack of interest from CITES Parties. In the case of the caterpillar fungus it is already known that this species is subject to a significant level of trade because of its high value (Stone, 2015), and it is categorized as Vulnerable on the IUCN Red List (Yang, 2020). Ecological factors could further exacerbate this vulnerability. Specifically, the caterpillar fungus is host-specific on moths, feeds on the roots of grasses and herbaceous plants and has a limited geographical range (Wang & Yao, 2011; Yang, 2020). Trade in the species is regulated to a degree through national legislation in its range countries. For example, in Nepal it is regulated under the Forests Act 2019, and the Nepal Gazette paper, part 3, 2018, mandates a royalty rate of 30,000 NPR/kg. Similarly, Yarsagumba Management (harvest and trade) Directives 2017 ensure that caterpillar fungus harvesters follow the allocated harvest time, duration and transfer permits to manage this harvest and trade. In India the harvest and trade of caterpillar fungus are regulated through permits, guidelines and policies of range states, although it is not listed under the Wild Life (Protection) Act (1972) (TRAFFIC, 2023). Similarly, the State Council of the People's Republic of China listed it as a threatened species in 1999 under the State Forestry Administration and Ministry of Agriculture, and its collection and trade are strictly regulated (Zhang et al., 2009). In Bhutan it is protected under Schedule 1 of the Forest and Nature Conservation Act (Cannon et al., 2009). The latter is being updated, and *Cordyceps* is being listed in Schedule II of the Forest and Nature Conservation Bill of Bhutan; this bill is under deliberation. Bhutan also has technical regulations on rewards, fines, harvest timing, quotas and other criteria to promote sustainable harvest (Cheung et al., 2005; DoFPS, 2018; Wangchuk et al., 2017; Byers et al., 2020).

These laws and listings have, however, been largely unsuccessful in regulating this trade, with natural resource managers (e.g. park officials, foresters, guards) having to deal with the issues of illegal trade (Shrestha et al., 2019; Byers et al., 2020). It has been estimated that 300–500 kg of caterpillar fungus annually are illegally traded on the international market (Cannon et al., 2009; Yadav et al., 2019). Monitoring this trade requires collective interventions and management plans from conservation agencies and governments (Zhang et al., 2012; Shrestha & Bawa, 2015), including training for harvesters (Byers et al., 2020).

The move of wildlife trade to online trade platforms has facilitated increased interactions between sellers, buyers and middlemen both nationally and internationally (Harrison et al., 2015), and provides opportunities for traders who were trading locally or nationally to have a global reach (Lee & Roberts, 2020). This creates additional challenges for overstretched wildlife enforcement officers monitoring trade, in particular of taxa such as plants and fungi (Whitehead et al., 2021). The internet, however, also provides researchers with an opportunity to study the engagement behaviours of consumers (Feddema et al., 2020), trading population parameters (William, 2018) and the structure and function of trade networks (Hinsley, 2016). Based on such information, conservation interventions, policy strategies and enforcement actions can be designed. As far as we are aware, there has been no previous study of the online caterpillar fungus trade, although Poudel et al. (2022) analysed newspaper coverage of caterpillar fungus-related news in the Nepali print media. Here we use a case study of the caterpillar fungus to document online trade using a systematic review approach. We checked English language platforms for sales advertisements of unprocessed whole caterpillars with fungal fruiting bodies or of caterpillar fungus in powdered form, to determine the extent and nature of the trade. This study is based on the number, frequency and nature of such advertisements, thus providing insights into the global market for and potential harvest pressure facing the caterpillar fungus.

Methods

Systematic online survey

This study followed the systematic survey approach for studying the online trade in wildlife (Roberts et al., 2021), which is based on the systematic evidence review approach (Higgins & Green, 2011). The study used search terms rather than browser-based strategies; therefore, it was important to identify search terms for 'taxa', 'trade behaviour' and 'product form'. The terms were in English, although widely used Nepali and Chinese Roman words for caterpillar fungus were also considered for 'taxa'.

We initially identified the most obvious search terms based on taxa and trade behaviour to be 'caterpillar fungus' and 'buy'. Using these we searched on Google (2021) to identify associated words using snowball sampling (Roberts et al., 2021). This approach led us to the following terms for 'taxa': *Cordyceps sinensis*, *Cordyceps*, *Ophiocordyceps*, Chinese caterpillar fungus, caterpillar herb, winter worm, summer grass, chong cao, worm herb, insect-plant, yarsagumba, yartsa gunbu, dōng chóng xià cǎo, yarsha-gumba, keeda jadi, bu, keera jhar, keeda jadi, keeda ghas, ghaas

fafoond, yartsa guenboob, chong cao, dōng chóng xià cǎo, tōchūkasō, aweto and vegetable caterpillar. Similarly, for 'trade behaviour' we identified search terms based on the item being traded or offered for sale, including the currency used. We identified the following terms associated with trade behaviour: buy, want, sale, available and price. In terms of the products advertised, we were interested in pure forms, either unprocessed or powdered. We listed the possible currencies as NPR (Nepalese rupee), INR (Indian rupee), GBP (British pound sterling), CNY (Chinese yuan renminbi), JPY (Japanese yen), USD (US dollar), EUR (euro) and ISL (new Israeli shekel).

After we had compiled a list of all possible search terms, we contacted 15 academics based in China, India and Nepal who we knew had researched caterpillar fungus, asking the following questions: (1) 'From these terms (or others you might know), which three words would you pick if you were to search for caterpillar fungus online?' (2) 'Rank these trade terms in order of importance for the same search.' We received 10 responses, based on which we selected the search terms 'yarsagumba', 'caterpillar fungus' and '*Ophiocordyceps sinensis*', along with the trade behaviour word 'buy'.

Search strategy and data collection

We conducted a pilot survey over a 15-day period during July 2021 using combination of search terms such as 'yarsagumba' and 'buy', 'caterpillar fungus' and 'buy', and '*Ophiocordyceps sinensis*' and 'buy'. We undertook this using the Google (2021) search engine, with the first four URLs (amazon.com, alibaba.com, daraz.com and indiamart.com) assessed for relevance. We collected data from all possible searches using the search terms conducted on these platforms. For example, if we found an advertisement on Amazon during the search, we conducted other searches on the same site.

In the pilot survey we found 20 advertisements for caterpillar fungus, including information on the date of advertisements, seller name/telephone number, quantity available, specification of the item (weight, length), grade, price, currency, unit, order size, platform, URL, country/city of trade and shipping. This survey helped us understand the type of data available and identify the platforms where this trade was taking place and where on the advertisements to look for relevant data, and to prepare a search strategy on such platforms.

We collected some identification details during the survey, such as the URL of the advertisement and the seller/company name. We did not register our profile as a potential buyer on the platforms nor did we message any sellers, and thus we only collected details that were publicly available. We only used data considered personal, such as seller name, during the process of data cleaning and segregation, to enable the removal of duplicate advertisements and thereby reduce issues of non-independence in the analysis.

Following the pilot survey, we conducted a 4-month survey during September–December 2021. Our searches included all advertisements offering items for sale throughout 2021. For the first 3 months of the survey, we considered only those advertisements that had unprocessed caterpillar fungus. However, we found many advertisements in which the fungus had been processed into a powdered form, and for the final month we therefore also recorded trade in powdered caterpillar fungus. For each advertisement we recorded the variables described in Table 1.

Data screening

We focused on all trade instances where the caterpillar fungus could have been purchased. Although we collected advertisements that did not have information on price, we excluded those that stated the item was out of stock. We did not deliberately exclude any specific platforms.

In total we located 180 advertisements, of which 13 lacked price details, 47 had a range for the price and the remaining had a fixed price. The prices were presented in six currencies: NPR, INR, USD, GBP, EUR and ISL. To standardize the prices, we converted these into USD based on the conversion rate of OANDA (2021): 1 NPR = 0.00824 USD, 1 INR = 0.01332 USD, 1 GBP = 1.33138 USD, 1 EUR = 1.13254 USD and 1 INR = 0.31608 USD.

We also excluded from the analysis two advertisements of caterpillar fungus as a liquid in Ukraine and the UK through eBay and Amazon, respectively, and 10 advertisements that offered caterpillar fungus as pieces rather than by weight as we could not convert this to a standard unit. This resulted in a total of 168 advertisements that we included in the analysis.

We found that the terms 'pharmaceuticals' and 'medicine' were used interchangeably in advertisements, and we combined these in the analysis as 'medicine'. We also found sellers advertising the same products (with the same details on price, images, place of origin, etc.) in what appeared to be duplicates, and we therefore considered them as one.

Data analysis

For the 47 advertisements that had prices in form of a range, we used the mid-point of the minimum and maximum price. Price was not normally distributed in either the original data (Shapiro–Wilk normality test $W = 0.60413$, $P < 2.2 \times 10^{-16}$) or the log-transformed data ($W = 0.87046$, $P = 2 \times 10^{-10}$). We conducted the analysis using *R 4.1.2* (R Core Team, 2021).

TABLE 1 Description of variables recorded for each online caterpillar fungus *Ophiocordyceps sinensis* advertisement during 2021.

Variable	Description
Date	Date advertisement was placed
Seller name/telephone	At least one kind of identification detail to avoid duplicates
Quantity	Amount of caterpillar fungus offered for sale
Specification of item	Weight & length of item advertised
Grade	Type of grade or quality of item advertised
Price & currency	Price of item (total & unit price) & currency
Order size	Minimum to maximum order that can be placed
Platform	E-commerce site where the item was advertised
Country of origin	Country where the item came from as indicated in the advertisement
Country of trade	Country where the seller &/or item were indicated as being located
City of trade	City where the seller &/or item were indicated as being located
Link	URL of the advertisement
Shipping	Physical movement of advertised item to buyer's destination

Results

Of the 168 advertisements, 98 contained the usernames of sellers, of which 78 had a single advertisement, 16 advertised caterpillar fungus twice, three advertised on three occasions and only one seller advertised on four occasions. The sellers confined their trade to a single platform (i.e. sellers did not appear to trade across multiple platforms).

Trade platforms

We identified trade on eight platforms: Alibaba, Amazon, Daraz, eBay, Etsy, IndiaMART, National Exports and Greenmandu (Fig. 1). Of these, advertisements were most common on Alibaba (71), IndiaMART (47) and eBay (27). Amazon, eBay and Etsy operate globally, Alibaba and IndiaMART are common in China and India respectively, and Daraz, National Exports and Greenmandu are based in Nepal.

Prices were comparatively higher on eBay, followed by Etsy and IndiaMART (Fig. 1). The highest prices were on international marketplaces, with one advertisement on Etsy selling caterpillar fungus for 154.95 USD/g (median price = 10.46 USD/g), followed by eBay at 135.00 USD/g (median price = 14.85 USD/g) and IndiaMART at 46.62 USD/g (median price = 14.64 USD/g). The highest price on a national marketplace was on National Exports at 23.00 USD/g (this was the only advertisement on that platform). Shipping and delivery were available for all of the advertisements. Etsy, eBay and Daraz imposed their standard delivery charge, but other platforms indicated they provided free shipping.

Caterpillar fungus grades

Caterpillar fungus was traded in various grades, although 76 advertisements did not mention a grade. The frequently used grades were food (31), pure/organic/wild (13) and top/best/premium (11). There was frequent use of the term A (as A+, A++, AA+, A+++, A, 2A or 3A), and some advertisements used B and ABC to indicate grade. Terms such as 'Himalaya', a combination of 'food' and 'medicine' and a combination of 'food', 'medicine' and 'cosmetic' were also used. We grouped grades into six categories: authentic (pure, organic, wild, Himalaya), consumption (medicine, food, cosmetic, beverages, etc.), food only, high grade (top, best, premium, A+, A, ABC, etc.), medicine only, and other (those advertisements that did not mention grade; Fig. 2).

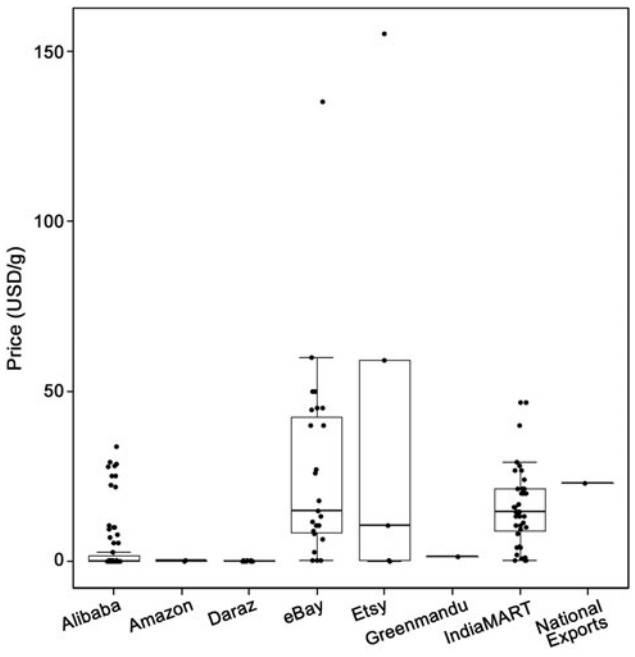

FIG. 1 Box plots comparing the price (in USD/g) of the caterpillar fungus *Ophiocordyceps sinensis* advertised on eight online trade platforms during 2021. The horizontal line indicates the median, the box the 1st and 3rd quartiles, the whiskers the minimum and maximum 1.5 interquartile ranges, and the dots outlying values.

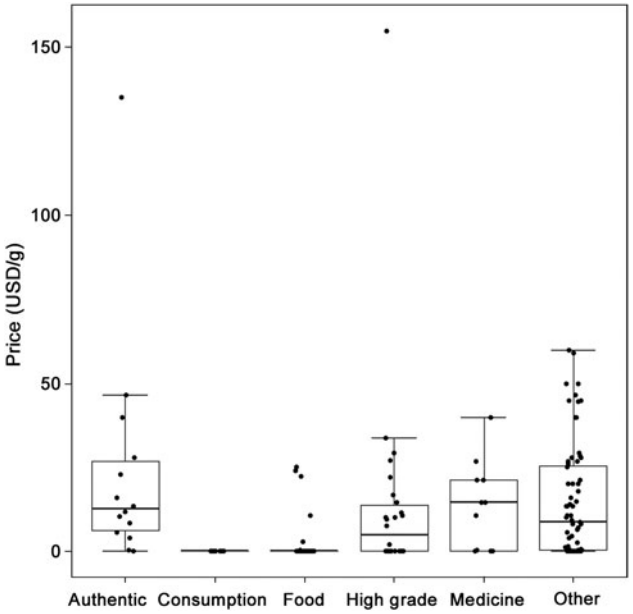

FIG. 2 Box plots comparing the price (in USD/g) for various grades of the caterpillar fungus advertised on eight online trade platforms during 2021. The horizontal line indicates the median, the box the 1st and 3rd quartiles, the whiskers the minimum and maximum 1.5 interquartile ranges, and the dots outlying values. Grade categories were obtained by grouping sub-grades: high grade (top, best, premium, A+, A++, A+++, A, 2A, 3A, ABC), authentic (pure, organic, wild, Himalaya), consumption (medicine, food, cosmetic, beverages), food only, medicine only and other (advertisements without grades).

The caterpillar fungus that we categorized as 'authentic' had the highest median price (24.45 USD/g), followed by A/A++ (17.20 USD/g), medicine grade (11.51 USD/g) and top/best/premium grade (9.26 USD/g). There were eight advertisements labelled as a mix of different grades (medicine, food, cosmetic, beverage) and they had the lowest median price (0.04 USD/g). There were many advertisements labelled food grade, and they had low median prices (2.80 USD/g; Fig. 2).

An advertisement labelled A+++ (which we categorized as high grade), on eBay, had the highest sale price (154.95 USD/g). Advertisements labelled pure, organic or wild carried high prices on eBay and IndiaMART. Advertisements on Daraz and Greenmandu did not indicate grades, and National Exports (which had the highest prices of the three Nepali platforms) referred to organic grade.

Price

The median price of caterpillar fungus in all advertisements was 2.67 USD/g (minimum 0.01 USD/g; maximum 154.95 USD/g). Caterpillar fungus was sold unprocessed (n = 86) or powdered (n = 82). The median price of the unprocessed form (23.33 USD/g) was greater than that of the powdered form (0.43 USD/g; Fig. 3). Four advertisements, all for unprocessed caterpillar fungus, had prices > 50.00 USD/g: 59.05 USD/g on Etsy, 60.00 USD/g on eBay, 135.00 USD/g on eBay and 154.95 USD/g on Etsy.

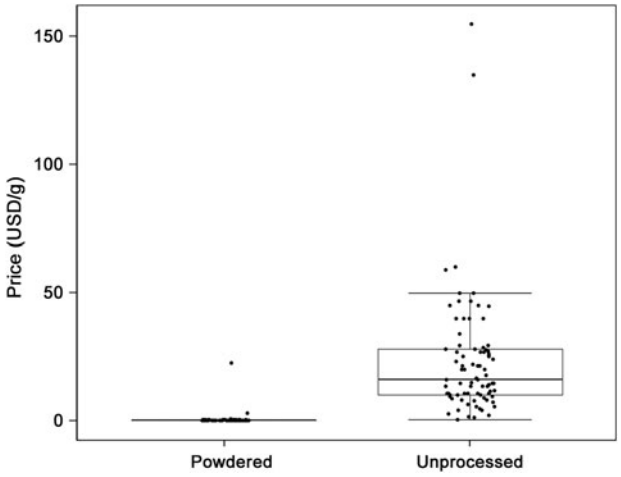

FIG. 3 Box plots comparing the price (in USD/g) for powdered and unprocessed caterpillar fungus offered for sale on eight online trade platforms during 2021. The horizontal line indicates the median, the box the 1st and 3rd quartiles, the whiskers the minimum and maximum 1.5 interquartile ranges, and the dots outlying values.

Countries of origin and trade

Country of origin was indicated as China in 70 advertisements, as India in 39 and as Nepal in 21. Twenty-three advertisements did not indicate country of origin, and one advertisement indicated several countries (Nepal, Bhutan, China, India) as country of origin.

The median price was highest for caterpillar fungus originating from Bhutan (47.07 USD/g), followed by Tibet (31.04 USD/g). Three advertisements mentioned the USA as their country of origin, with a median price of 9.31 USD/g. Caterpillar fungus originating from Nepal had a median price of 7.18 USD/g, those originating from China had a median price of 7.75 USD/g and those originating from India had a median price of 15.42 USD/g.

Caterpillar fungus was sold from 11 countries: Canada, China, Germany, India, Ireland, Nepal, Slovenia, UK, Ukraine, USA and Viet Nam (four advertisements did not indicate country of trade) either powdered or unprocessed (Fig. 4). Prices varied depending upon the country of trade and whether the fungus was powdered or unprocessed.

Discussion

The online trade in the caterpillar fungus on English language websites appears to be dominated by Alibaba (a Chinese e-commerce platform) followed by IndiaMART (an Indian e-commerce platform). Alibaba is the largest e-commerce platform in China, and it has campaigned

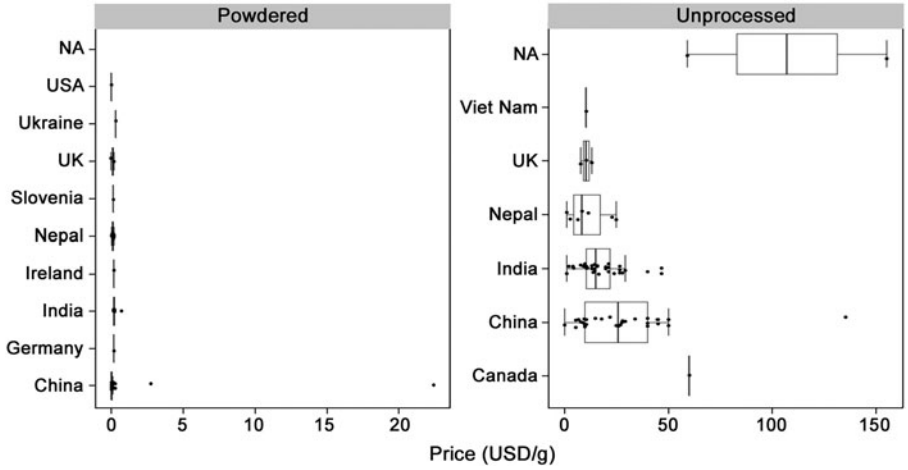

FIG. 4 Box plots comparing price (in USD/g) for powdered and unprocessed caterpillar fungus advertised on eight online trade platforms during 2021, based on country of trade. The horizontal line indicates the median, the box the 1st and 3rd quartiles, the whiskers the minimum and maximum 1.5 interquartile ranges, and dots the outlying values. Note the different scales. NA, advertisements that did not indicate the country of trade.

with TRAFFIC to monitor wildlife trade. However, this campaign seems to have been focused on animals, with trade of illegally obtained plants such as orchids continuing (Wong & Liu, 2019), suggesting the same could be the case for caterpillar fungus.

We found that the caterpillar fungus was sold for prices as high as 154.95 USD/g on Etsy and 135.00 USD/g on eBay. Both eBay and Etsy are international platforms with high sales engagement, and this suggests international buyers are potentially willing to pay high prices for the caterpillar fungus. The differences in advertised prices on different platforms could be because of opportunistic or immature markets, in which vendors test the markets with unrealistic prices, as has been reported for saiga horn (Roberts et al., 2021). Forty-six per cent of sellers had only one advertisement, on one platform, which also shows that traders may have a specific niche in terms of their choice of platform and the number of advertisements they place. Caterpillar fungus is also sold at varying prices in the informal market (Pant et al., 2020), although its trade in physical markets appears well structured in terms of price. We recommend that further studies examine relationships between price and trade patterns before drawing any conclusions on price differences between platforms.

The advertisements presented the grade of caterpillar fungus as a major indicator of quality and hence price difference, although there was no evidence of third-party monitoring to ensure the grading advertised was not fraudulent. The terms referring to higher grades and greater authenticity had the highest prices, and those mentioning consumption and food only grade had the lowest prices (Fig. 2). A previous study demonstrated that top-quality caterpillar fungus is priced as high as 12,500 USD/kg (Cannon et al., 2009), and prices for caterpillar fungus in India varied depending on the grade (Negi et al., 2015). We did not find any convention in the use of grades; it appears that the sellers were experimenting with terms, to attract buyers. Studies have suggested that consumers prefer to buy caterpillar fungus of Himalayan origin, driven by a misconception of product efficacy (He et al., 2022). The high price for caterpillar fungus originating from the Himalayas is attributed to its origin at high altitudes (Holliday & Cleaver, 2008). We found, however, that the use of 'Himalayan' did not always indicate a Himalayan country of origin.

We found that the caterpillar fungus was being sold in 11 countries and sourced from several Himalayan countries. In some of the trade countries (Canada, Slovenia, UK and USA), caterpillar fungus does not occur in the wild, and this trade mainly occurred on the global e-commerce platforms eBay and Amazon. In countries such as Nepal, where trade in commodities is increasingly occurring online (Devkota et al., 2021), we found 12 advertisements on the Nepali e-commerce platforms Daraz and National Exports, which are only for Nepali consumers. Although most of the caterpillar fungus harvested in Nepal is exported (Pant et al., 2020), the price recorded on one of the Nepali platforms, National Exports, was 23 USD/g. A herbal trader based in Kathmandu informed us that rich domestic buyers do not compromise on quality and are willing to pay high prices for caterpillar fungus (P. Lama, pers. comm., 2022).

The online advertisements for caterpillar fungus did not mention whether the material was harvested sustainably. This is important because harvest sites in the Himalayas face intense pressure from unsustainable and destructive harvesting to meet global demand (Wang & Yao, 2011; Childs & Choedup, 2014; Negi et al., 2015). The impacts of overharvesting are intensifying as collectors extract caterpillars with immature fungi (before the fungus begins to produce spores) as well as those with reproductively mature fungi (Belwal et al., 2019; Yadav et al., 2019), which could potentially drive the collapse of the harvest (Shrestha et al., 2014). The consequences of this are already evident, as the caterpillar fungus yield has declined in China (Winkler, 2009), Nepal (Shrestha & Bawa, 2013) and globally (Shrestha & Bawa, 2015; Yadav et al., 2019).

Travel bans and border closures during the Covid-19 pandemic resulted in the expansion of wildlife trade online

(Morcatty et al., 2021). The pandemic also increased public interest in wildlife trade because of the purported link between Covid-19 and wet wildlife markets (Roe et al., 2020) and increased online discussion of wildlife (Morcatty et al., 2021). The online trade we documented was probably affected by the pandemic because there were restrictions on movement and on physical markets in major cities, but such restrictions were probably ineffective in remote areas. Caterpillar fungus harvest in Nepal continued despite travel bans (Paudel, 2023).

Non-charismatic taxa such as plants and fungi are subject to large-scale international trade, yet there are no fungal species listed on the CITES Appendices. Trade in plants and fungi is also poorly documented because of plant and fungal blindness (Phelps & Webb, 2015), and is also underrepresented in seizures (Paudel et al., 2022). This highlights the need for more research and legislation attention for these taxa (Goncalves et al., 2021; Oyanedel et al., 2022) and for more attention to be focused on the growing online trade. Our research shows that the caterpillar fungus is traded over the internet to meet both domestic and international demand, but the detection of illegal online trade is challenging as traders may use coded terms and phrases (Alfino & Roberts, 2020). The limited capacity to detect the legality and sustainability of such trade, especially in countries such as Nepal, adds to the challenge. Although the application of artificial intelligence tools has been suggested as a way to address the challenges (Di Minin et al., 2018), few such tools have materialized, and most lack the ability to monitor large volumes of data.

Conclusion

Despite the considerable focus on the economic significance of the caterpillar fungus, there has been little attention dedicated to this species concerning research on illegal wildlife trade and policy. As the fungus is not listed in the CITES appendices, there are challenges to improving governance of this trade in the species' Himalayan range. The trade is also moving online, posing a more complex challenge for regulation. In the context of limited conservation attention on plants and fungi and little capacity to track online trade, the burgeoning trade in the caterpillar fungus is potentially detrimental both to the sustainability of the fungus and to the livelihoods of the harvesters. With increasing reach and usage of the internet, trade in other non-charismatic taxa is probably also increasing online. We recommend further systematic evaluations of online trade in plants and fungi, to improve conservation interventions and to prevent future expansion of illegal wildlife trade in online markets.

Acknowledgements We thank the experts who took part in our survey during the selection of search terms; Greenhood Nepal colleague K. Paudel for providing advice regarding study design and ethical approval; and the editor of *Oryx* and two anonymous reviewers for their constructive comments. This research received no specific grant from any funding agencies or commercial or not-for-profit sectors.

Author contributions Conception: both authors; data collection and analysis: RB; writing: both authors.

Conflicts of interest None.

Ethical standards This study was approved by the Ethics Committee of Greenhood Nepal (code G07903), and the research abided by the *Oryx* guidelines on ethical standards. We did not collect personal details of sellers, but we stored hyperlinks until we cleaned our data for further analysis. The data were shared exclusively between the two co-authors.

Data availability The data that support the findings of this study are available on request from RB. The data are not publicly available because of ethical restrictions.

References

Adhikari, K. (2009) *Himalayan Viagra: the consequences of the exploitation of yarsagumba (*Cordyceps sinensis*)*. MSc thesis. University of Aberdeen, Aberdeen, UK.

Alfino, S. & Roberts, D.L. (2020) Code word usage in the online ivory trade across four European Union member states. *Oryx*, 54, 494–498.

Belwal, T., Bhatt, I.D., Kashyap, D., Sak, K., Tuli, H.S., Pathak, R. et al. (2019) *Ophiocordyceps sinensis*. In *Nonvitamin and Nonmineral Nutritional Supplements* (eds S.M. Nabavi & A.S. Silva), pp. 527–537. Academic Press, Cambridge, USA.

Bista, S. & Webb, E.L. (2006) Collection and marketing of non-timber forest products in the far western hills of Nepal. *Environmental Conservation*, 33, 244–255.

Byers, A.C., Byers, E., Shrestha, M., Thapa, D. & Sharma, B. (2020). Impacts of yartsa gunbu harvesting on alpine ecosystems in the Barun Valley, Makalu Barun National Park, Nepal. *Himalaya*, 39, 44–59.

Cannon, P.F., Hywel-Jones, N.L., Maczey, N., Norbu, L., Tshitila, Samdup, T. & Lhendup, P. (2009) Steps towards sustainable harvest of *Ophiocordyceps sinensis* in Bhutan. *Biodiversity and Conservation*, 18, 2263–2281.

Cheung, J., Li, S.P. & Tsim, K. (2005) Authentication and quality control *of Cordyceps sinensis*, a traditional Chinese medicine known as winter worm summer grass. *Oriental Pharmacy and Experimental Medicine*, 5, 262–271.

Childs, G. & Choedup, N. (2014) Indigenous management strategies and socioeconomic impacts of yartsa gunbu (*Ophiocordyceps sinensis*) harvesting in Nubri and Tsum, Nepal. *Himalaya*, 34, 8–22.

Devkota, S. (1970) Yarsagumba (*Cordyceps sinensis*); traditional utilization in Dolpa District, western Nepal. *Our Nature*, 4, 48–52.

Devkota, N., Budhathoki, A., Paudel, U.R., Adhikari, D.B., Bhandari, U. & Parajuli, S. (2021) Online trading effectiveness in Nepal share market: investors awareness, challenges and managerial solution. *Asian Journal of Economics, Business and Accounting*, 21, 90–98.

Di Minin, E., Fink, C., Tenkanen, H. & Hiippala, T. (2018) Machine learning for tracking illegal wildlife trade on social media. *Nature Ecology and Evolution*, 2, 406–407.

DOFPS (Department of Forests & Park Services) (2018) Guidelines for collection/harvesting of *Ophiocordyceps sinensis* for

2018. Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan, Thimphu, Bhutan.

Feddema, K., Harrigan, P., Nekaris, K.A.I. & Maghrifani, D. (2020) Consumer engagement behaviors in the online wildlife trade: implications for conservationists. *Psychology and Marketing*, 37, 1755–1770.

Fukushima, C.S., Mammola, S. & Cardoso, P. (2020) Global wildlife trade permeates the tree of life. *Biological Conservation*, 247, 108503.

Goncalves, S.C., Haelewaters, D., Furci, G. & Mueller, G.M. (2021) Include all fungi in biodiversity goals. *Science*, 373, 403.

Google (2021) Google.com [accessed July 2021].

Harrison, M., Baker, J., Twinamatsiko, M. & Milner-Gulland, E.J. (2015) Profiling unauthorized natural resource users for better targeting of conservation interventions. *Conservation Biology*, 29, 1636–1646.

He, J., Smith-Hall, C., Zhou, W., Wang, Y. & Fan, B. (2022) Uncovering caterpillar fungus (*Ophiocordyceps sinensis*) consumption patterns and linking them to conservation interventions. *Conservation Science and Practice*, 4, 1–9.

Higgins, J.P.T. & Green, S. (eds) (2011) *Cochrane Handbook for Systematic Reviews of Interventions*. Version 5.1. The Cochrane Collaboration, London, UK. handbook-5-1.cochrane.org [accessed 21 July 2021].

Hinsley, A. (2016) *Characterising the structure and function of international wildlife trade networks in the age of online communication*. PhD thesis. University of Kent, Canterbury, UK.

Holliday, J.C. & Cleaver, M. (2008) Medicinal value of the caterpillar fungi species of the genus *Cordyceps* (Fr.): a review. *International Journal of Medicinal Mushrooms*, 10, 219–234.

Hopping, K.A., Chignell, S.M. & Lambin, E.F. (2018) The demise of caterpillar fungus in the Himalayan region due to climate change and overharvesting. *Proceedings of the National Academy of Sciences of the United States of America*, 115, 11489–11494.

Karki, R., Kandel, K., Kunwar, A., Bhatta, J., Panthi, S. & Pant, P.K. (2020) Yarsagumba collection and marketing: a key income source of people in Api Nampa conservation area, Darchula, Nepal. *Journal of Agriculture and Natural Resources*, 3, 219–232.

Lee, T.E. & Roberts, D.L. (2020) Moving beyond simple descriptive statistics in the analysis of online wildlife trade: an example from clustering and ordination. *Tropical Conservation Science*, 2020, 13.

Margulies, J.D., Bullough, L., Hinsley, A., Ingram, D.J., Cowell, C., Goettsch, B. et al. (2019) Illegal wildlife trade and the persistence of 'plant blindness'. *Plants, People, Planet*, 1, 173–182.

Morcatty, T.Q., Feddema, K., Nekaris, K.A.I. & Nijman, V. (2021) Online trade in wildlife and the lack of response to COVID-19. *Environmental Research*, 193, 110439.

Negi, C.S., Joshi, P. & Bohra, S. (2015) Rapid vulnerability assessment of yartsa gunbu (*Ophiocordyceps sinensis*) in Pithoragarh District, Uttarakhand State, India. *Mountain Research and Development*, 35, 382–391.

OANDA (2021) oanda.com [accessed 1 December 2021].

Oyanedel, R., Hinsley, A., Dentinger, B.T.M., Milner-Gulland, E.J. & Furci, G. (2022) A way forward for wild fungi in international sustainability policy. *Conservation Letters*, 15, e12882.

Pant, B., Kumar Rai, R., Bhattarai, S., Neupane, N., Kotru, R. & Pyakurel, D. (2020) Actors in customary and modern trade of caterpillar fungus in Nepalese high mountains: who holds the power? *Green Finance*, 2, 373–391.

Pant, B., Rai, R.K., Wallrapp, C., Ghate, R., Shrestha, U.B. & Ram, A. (2017) Horizontal integration of multiple institutions: solutions for Yarshagumba related conflict in the Himalayan region of Nepal? *International Journal of the Commons*, 11, 464.

Paudel, S. (2023) *Assessing the economic impacts of COVID-19 pandemic on yarsagumba dependent community*. MSc thesis. Institute of Forestry, Tribhuvan University, Kathmandu, Nepal.

Paudel, K., Hinsley, A., Veríssimo, D. & Milner-Gulland, E. (2022) Evaluating the reliability of media reports for gathering information about illegal wildlife trade seizures. *PeerJ*, 10, 1–18.

Phelps, J. & Webb, E.L. (2015) 'Invisible' wildlife trades: Southeast Asia's undocumented illegal trade in wild ornamental plants. *Biological Conservation*, 186, 296–305.

Poudel, S., Shrestha, U.B., Pandit, R. & Dhital, K.R. (2022) Communicating conservation: how do the Nepalese print media portray caterpillar fungus? An analysis of newspaper coverage from 2008–2021. *Heliyon*, 8, e10439.

R Core Team (2021) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. r-project.org/foundation [accessed January 2021].

Roberts, D.L., Mun, K. & Milner-Gulland, E.J. (2021) A systematic survey of online trade: trade in Saiga antelope horn on Russian-language websites. *Oryx*, 56, 352–359.

Roe, D., Dickman, A., Kock, R., Milner-Gulland, E.J., Rihoy, E. & 't Sas-Rolfes, M. (2020) Beyond banning wildlife trade: COVID-19, conservation and development. *World Development*, 136, 105121.

Shrestha, U.B. & Bawa, K.S. (2013) Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. *Biological Conservation*, 159, 514–520.

Shrestha, U.B. & Bawa, K.S. (2014) Economic contribution of Chinese caterpillar fungus to the livelihoods of mountain communities in Nepal. *Biological Conservation*, 177, 194–202.

Shrestha, U.B. & Bawa, K.S. (2015) Harvesters' perceptions of population status and conservation of Chinese caterpillar fungus in the Dolpa region of Nepal. *Regional Environmental Change*, 15, 1731–1741.

Shrestha, U.B., Dhital, K.R. & Gautam, A.P. (2019) Economic dependence of mountain communities on Chinese caterpillar fungus *Ophiocordyceps sinensis* (yarsagumba): a case from western Nepal. *Oryx*, 53, 256–264.

Shrestha, U.B., Shrestha, S., Ghimire, S., Nepali, K. & Shrestha, B.B. (2014) Chasing Chinese caterpillar fungus (*Ophiocordyceps sinensis*) harvesters in the Himalayas: harvesting practice and its conservation implications in western Nepal. *Society and Natural Resources*, 27, 1242–1256.

Stone, N. (2015) *The Himalayan Gold Rush: The Untold Consequences of Yartsa Gunbu in the Tarap Valley*. School for International Training Study Abroad, Brattleboro, USA.

Thapa, B.B., Panthi, S., Rai, R.K., Shrestha, U.B., Aryal, A., Shrestha, S. & Shrestha, B. (2014) An assessment of yarsagumba (*Ophiocordyceps sinensis*) collection in Dhorpatan Hunting Reserve, Nepal. *Journal of Mountain Science*, 11, 555–562.

TRAFFIC (2023) *Factsheet on India's Caterpillar Fungus in Illegal Wildlife Trade*. TRAFFIC India Office, New Delhi, India. traffic.org/publications/reports/factsheet-on-indias-caterpillar-fungus-in-illegal-wildlife-trade [accessed 13 November 2023].

UNODC (2016) *World Wildlife Crime Report*. United Nations Office on Drugs and Crime, Vienna, Austria.

Wang, Z., Da, W., Negi, C.S., Ghimire, P.L., Wangdi, K., Yadav, P.K. et al. (2022) Profiling, monitoring and conserving caterpillar fungus in the Himalayan region using anchored hybrid enrichment markers. *Proceedings of the Royal Society B: Biological Sciences*, 289, 20212650.

Wang, X.L. & Yao, Y.J. (2011) Host insect species of *Ophiocordyceps sinensis*: a review. *ZooKeys*, 127, 43–59.

Wangchuk, S., Tenzin, J. & Thukten, K. (2017) *Review of Cordyceps Collection Timing, Duration and Monitoring*. Ugyen Wangchuck

Institute for Conservation and Environmental Research, Lamai Goempa, Bumthang, Bhutan.

Whitehead, D., Cowell, C.R., Lavorgna, A. & Middleton, S.E. (2021) Countering plant crime online: cross-disciplinary collaboration in the FloraGuard study. *Forensic Science International: Animals and Environments*, 1, 100007.

William, J. (2018) *Characterising the extent of illegal online trade in wildlife using novel approaches*. PhD thesis. University of Kent, Canterbury, UK.

Winkler, D. (2009) Caterpillar fungus (*Ophiocordyceps sinensis*) production and sustainability on the Tibetan Plateau and in the Himalayas. *Asian Medicine*, 5, 291–316.

Wong, S. & Liu, H. (2019) Wild-orchid trade in a Chinese e-commerce market. *Economic Botany*, 73, 357–374.

Yadav, P.K., Saha, S., Mishra, A.K., Kapoor, M., Kaneria, M., Kaneria, M. et al. (2019) Yartsagunbu: transforming people's livelihoods in the Western Himalaya. *Oryx*, 53, 247–255.

Yang, Z.-L. (2020). *Ophiocordyceps sinensis*. In *The IUCN Red List of Threatened Species* 2020. dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T58514773A179197748.en.

Zhang, Y., Li, E., Wang, C., Li, Y. & Liu, X. (2012) *Ophiocordyceps sinensis*, the flagship fungus of China: terminology, life strategy and ecology. *Mycology*, 3, 2–10.

Zhang, Y., Xu, L., Zhang, S., Liu, X., An, Z., Wang, M. & Guo, Y. (2009) Genetic diversity of *Ophiocordyceps sinensis*, a medicinal fungus endemic to the Tibetan Plateau: implications for its evolution and conservation. *BMC Evolutionary Biology*, 9, 1–12.