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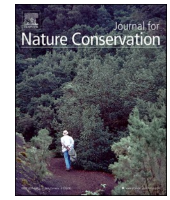

Assessing the identification uncertainty in plant products traded as traditional Asian medicines

Reshu Bashyal [a,b,*], David L. Roberts [b]

[a] Greenhood Nepal, New Baneshwor, Kathmandu, Nepal
[b] Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, Marlowe Building, University of Kent, Canterbury, Kent, CT2 7NR, United Kingdom

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ABSTRACT

Biodiversity is threatened by multiple factors including habitat loss, climate change, and over-exploitation. The illegal wildlife trade is one of the key threats to species survival and its regulation and monitoring are dependent on accurate identification. Plants are particularly difficult to identify due to their look-alike properties, which are further aggravated when they are processed eventually in their finished product. Identification of species is critical to monitoring, detecting, and regulating the wildlife trade. In this study, we quantified species misidentification using a match-mismatch experiment adapted from psychology, taking examples of medicinal plant products used in Traditional Asian Medicines. Participants compared 210 pairs of images of plant products, indicating if the paired images were the same (species), different (species), or (they) did not know. We found that the matched pairs (paired images of the same species) had a lower level of error than the unmatched pairs (paired images of different species). Similarly, 1.4% of the image pairs had errors over 75%, three of them as high as 83%. Such errors in species identification can be used by traders to deceive enforcement actions through laundering as less threatened or regulated species. These results suggest that future interventions around identification training should prioritize species with high errors and should consider that product processing may have a significant impact on identification. Further, initiatives related to species identification could benefit from using existing standard methodologies from psychology to inform training needs and measure their impacts which in turn will benefit conservation efforts.

1. Introduction

Wildlife trade is a billion-dollar with millions of organisms being traded legally each year under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Harfoot et al., 2018). There is also a significant amount of illegal wildlife trade (IWT) although with no exact estimation of species and quantities involved (Sas-Rolfes et al., 2019). Wildlife, its parts, and derivatives are traded for various purposes, including traditional medicines, which are relied upon by over 70% of rural populations in developing nations (FAO, 2005; Sheng-Ji, 2001). The association of the COVID-19 pandemic with zoonotic disease transmission risks via live wildlife markets, wild meat processing, and consumption has renewed interest in the global wildlife trade. Moreover, the use of traditional medicines, including plant products, and official endorsement by the Chinese guidelines on the treatment of COVID-19 (Liu et al., 2020; Rastogi et al., 2020) have increased attention to the wildlife trade.

The global trade in medicinal plants is substantial. According to Schippmann et al. (2007), at least 72000 plant species are (reportedly) used for their medicinal values. Many medicinal plant species are subject to CITES and a high proportion of these are wild-harvested. CITES (2022)- medicinal and aromatic plants mention that an estimated 1280 medicinal and aromatic species are listed in CITES Appendices, while Timoshyna et al. (2020) note over 800 medicinal and aromatic species are listed in CITES Appendix II and that 60-90% of medicinal and aromatic plants in trade are collected from the wild. The trade of medicinal plant products is expected to rise dramatically. This is also evident from the recent increase in the seizure of medicinal commodities as reported by Timoshyna et al. (2020). This increased use of plant-derived medicinal could be due to heightened health concerns associated with COVID-19. The use of herbal supplements including traditional Chinese medicines is increasing (Hinsley et al., 2019), tripling in value over the past

* Corresponding author at: Greenhood Nepal, New Baneshwor, Kathmandu, Nepal
E-mail address: bashyalreshu@gmail.com (R. Bashyal).

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two decades to USD 3.3 billion by 2018 (Timoshyna et al., 2019).

Plants have been largely ignored in terms of the IWT demand reduction campaigns,

despite representing approximately 84% of all species listed under the CITES legislation (Sas-Rolfes et al., 2019). Owing to this "plant blindness", the phenomenon where people ignore plants in favor of animals, little is known about which plants are being traded and in what form (Margulies et al., 2019). In addition to that, globally, 10-20% of plant species remain unknown to science, however, the vast majority of plants are likely to be naturally rare and threatened with extinction (Joppa et al., 2011). Activities such as the description of new species, population size estimation, conservation prioritization, and sustainable utilization, rely on accurate species identification (Mackay-Smith and Roberts, 2019; Wäldchen et al., 2018). From a human health perspective, the correct identification of plant species is crucial as misidentification can lead to serious health conditions. For example, the poisonous plant, *Conium maculatum* (Hemlock), resembles the edible vegetable parsley (Konca et al., 2014), while Chinese Pharmacopoeia (2015) lists over 75 plant species that are poisonous and are often confused or misidentified with similar edible plant species (Liu et al., 2019).

Taxonomic misidentification is also a tool used by illicit traders to launder species. This includes both the deliberate incorrect labeling of protected logs as a species of lesser concern (Wiedenhoeft et al., 2019) and camouflaging the protected plant with other (Pyakurel et al., 2019). Alfino and Roberts (2019) found that some species of chameleon from the genus *Calumma* were available in the online trade despite being subject to a zero quota (ban from trading) under CITES, potentially due to it being laundered as a similar-looking species for which a quota exists. This genus of chameleon is listed in CITES Appendix II/EU Annex B with some species from the genus subject to a zero quota (e.g. *C. globifer*). As such, not all species are equally misidentified. When people use these practices to mislead enforcement agencies, identification becomes a barrier to enforcement and other stakeholders addressing plant trade (Margulies et al., 2019).

Beyond species, in plants, parts such as roots and rhizomes are widely misidentified. This is, largely because of the lack of morphological features compared with vegetative and reproductive parts (Wiedenhoeft et al., 2019). Further, species identification is complicated when their parts are further transformed into processed products. For example, the orchid genus, *Dendrobium* may be easily identifiable when traded as a live plant, but identification becomes challenging when it is traded as stems, or when its stems are dried and powdered to form capsules (Fay, 2015; Liu et al., 2020).

Despite the importance of identification, understanding the nature of accurate identification remains poorly studied. In many cases, the taxonomic resources essential to accurate identification are unavailable, although the species are formally described (Gaston and O'Neill 2004). However, there is a growing interest among plant biologists for accurate species identification (Hopper, 2011). While manual techniques like field guides (Sanz et al., 2013; Wäldchen et al., 2018), image comparison (Swanson et al., 2016), and automated tools (Wäldchen et al., 2018) can be used to aid accurate species identification, errors can still occur and therefore understanding the distribution of such errors is important.

Match-mismatch experiment is a standard experimental design in psychology where it is most frequently used for face-matching tasks such as in experiments related to passport controls (White et al., 2014). This method is increasingly being used in conservation to explore issues of misidentification of different individuals and species (e.g. Gibbon et al., 2015), expert groups (e.g. Austen et al., 2016), and different features presented for identification (e.g. Gibbon et al., 2015). In this study, we used a match-mismatch experiment to study the patterns of misidentification of 20 medicinal plant species, specifically their tradable products (parts and derivatives).

2. Material and Methods

This research received ethical approval from the Research and Ethics Committee of the School of Anthropology and Conservation, University of Kent.

2.1. Plant samples and study participants

A sample of 100 Traditional Asian Medicines (TAMs) were bought from a single reputable licensed dealer in the UK. Each product represented one plant species. These were received in small sample bags and represented a range of species, processed in various tradable forms (e.g. crushed leaves, dried stems, dried bulbs). The reason for using only a single sample from a single trader was to ensure that what we were using was the same TAM product, as buying from different suppliers could have introduced the potential for misidentification. Of these species, a sample of 20 was randomly selected (Appendix A). The species came with botanical names on their labels but they were relabeled for uniformity following the universally accepted database the Plants of World Online (POWO) and the World Flora Online (WFO).

The respondents of this survey were university students of Natural Science in general. Students are a valid study group as customs and wildlife officers will not be specialists in TAMs and are unlikely to be users. They were identified based on convenience sampling involving a snowball approach. We did not stratify the sample to capture respondents with a variety of abilities to match species. The identified respondents were emailed explaining the purpose of research and their roles. Only those who agreed were selected and assigned to one of two image pair sets (set A and set B) (Appendix B). Of those approached 95% agreed to participate in the survey.

2.2. Match-mismatch experiment

We adopted a match-mismatch experiment format. It is a well-established approach within psychology for studying face recognition (Bindemann and Sandford, 2011; Kemp et al., 1997; White et al., 2014), but has begun to be used to study species identification (e.g., Alfino and Roberts, 2019; Austen et al., 2016). As this research took place during the COVID-19 pandemic (June 2020), face to face experiments were not possible. The experiment was run as an online questionnaire following the same format as previous species identification studies (e.g. Austen et al., 2016).

We photographed each of the selected 20 species samples on a plain white background from the same angle. Each sample was photographed twice. Between each photograph the sample was mixed, this was to ensure that respondents were identifying whether the photographs represented the same species, rather than using image matching. This resulted in a total of 210 image pairs. Considering a large number of images, the order in which the participants received the image pairs was randomized twice i.e. questions were in a different order for each of the two sets of questions.

We used digital images rather than participants comparing the physical samples due to difficulties given the COVID-19 pandemic and to ensure we maximized the number of participants. It is important to note that using images is a valid medium for this experimental context given the rise in online trade where only images are available. Further, even when physical samples are available, it is likely that images from a guide would be used for comparison, or when a photograph is taken and sent to an expert for identification.

The questionnaire was delivered via Google Forms (see, Appendix B and Appendix D). A pilot study was conducted with university students (n = 7) in May 2020, and questions were refined based on their feedback. Before the survey, the university students (n = 40) were e-mailed explaining the details of this study, consent information, and a sample question. This way, they were familiar with the type of questions and what they are expected to do. All 40 respondents provided their consent to participate in the survey. The final questionnaire was disseminated during a 20-day period in June 2020.

The questionnaire began with several short questions about their eyesight, knowledge of traditional medicines, and species identification skills. This was followed by the match-mismatch experiments involving 210 image pairs. Each participant was asked if the paired image was the same, different, or don't know. Given a large number of image pairs, the order in which the participants received the image pairs was randomized twice. This helped us to arrange image pairs in each set of questionnaires. This allowed us to determine if fatigue biased the response to later image pairs. The participant had no time boundary and could go back and change their responses until they submitted the completed questionnaire. They were kept anonymous and could leave the survey at any point.

2.3. Data analysis

Only responses from respondents who reported having a normal vision and corrected vision (e.g. had classes or contact lenses) were included in the analysis.

The error rates for each of the image pairs were calculated in MS Excel to prepare matrices (Table 1). The correct responses were the "right answer" while other answers (incorrect answers and don't know) were considered to be the wrong responses (adopted from Kemp et al., 1997). The error for each respondent was calculated as the percentage of the total number of wrong answers per image pair divided by the total number of participants. Following the same procedure, the error rates for image pairs, and matched/unmatched pairs were calculated. We also calculated the difference in the error response and the position of the image pairs to determine the effect of fatigue on the error rate. Besides the species-specific error rates, we also calculated and compared the errors for different trade forms as 1) single forms like barks, leaves, roots, seeds, and stems, and 2) mixed forms like leaves and roots, leaves and stems, and so on.

A Mann-Whitney U Test was used to determine if there was a significant difference in error between the two questionnaire sets and whether there was a significant difference between matched and unmatched pairs. Non-parametric (Spearman's) Correlation test was used to analyze the self-declared expertise and their existing knowledge of species identification. Self-declared experts were those respondents who self-reported in the questionnaire that they had knowledge of plant species in terms of identification and/or medicinal usage. A Pearson Correlation was used to compare the actual and absolute difference between position and error rate. All data were analyzed using Microsoft Excel (2016) and the IBM SPSS Statistics package for Windows (Version 26).

3. Results

Of the 40 university students who took part in the experiment, 36 completed the questionnaire (set A = 19 and set B = 17). Of these, 6 respondents (set A = 4, set B = 2) were omitted as they had non-corrected vision, resulting in 30 respondents (set A = 15 and set B = 15).

3.1. Error between respondent sets

The average incorrect response (hereafter error) was higher in respondents of set B (30.7%, n = 15, SD = 27.81) than set A (21.0%, n = 15, SD = 19.20). However, based on a Mann-Whitney U Test, there was no significant difference in the response in the two different sets ($U_{15,15}$ = 96.5, p = 0.512), therefore, the two sets of results were combined for further analysis.

3.2. Fatigue and error

We analyzed the potential for fatigue, impacting error due to the use of 210 image pairs. Following a test for normality, there was no significant correlation between the error and the position of image pairs based on the actual values (r^2 = 0.001, n = 210, p = 0.642) or absolute values (r^2 = 0.003, n = 210, p = 0.646) (Appendix C).

Table 1
Error (%) among the 20 species[1] and its possible combinations (n = 210), calculated as the percentage of the total number of wrong responses per image pair divided by the total number of participants

Species	L. gra	V. yed	G. lit	A. hen	C. orc	L. str	G. ela	M. alb	P. arm	P. pre	A. pub	D. lon	L. luc	A. lap	S. fla	G. ura	S. div	P. gra	A. mem	P. pra
L. gra	10.0																			
V. yed	70.0	6.7																		
G. lit	23.3	36.7	10.0																	
A. hen	20.0	23.3	33.3	23.3																
C.orc	30.0	30.0	36.7	83.3	10.0															
L. str	20.0	30.0	26.7	23.3	26.7	16.7														
G. ela	16.7	23.3	23.3	16.7	26.7	30.0	10.0													
M. alb	20.0	20.0	16.7	40.0	30.0	13.3	23.3	6.7												
P. arm	20.0	13.3	23.3	23.3	23.3	20.0	26.7	16.7	10.0											
P. pre	20.0	20.0	20.0	23.3	20.0	16.7	16.7	10.0	83.3	13.3										
A. pub	33.3	30.0	63.3	30.0	30.0	43.3	16.7	10.0	16.7	23.3	13.3									
D. lon	20.0	30.0	43.3	40.0	33.3	30.0	63.3	23.3	23.3	26.7	53.3	6.7								
L. luc	40.0	30.0	16.7	16.7	33.3	16.7	26.7	16.7	26.7	20.0	20.0	23.3	3.3							
A. lap	23.3	23.3	16.7	20.0	16.7	26.7	30.0	30.0	23.3	13.3	16.7	23.3	20.0	3.3						
S. fla	30.0	20.0	23.3	13.3	10.0	30.0	23.3	40.0	13.3	6.7	23.3	23.3	26.7	50.0	6.7					
G. ura	20.0	26.7	26.7	16.7	20.0	40.0	33.3	26.7	16.7	23.3	16.7	30.0	23.3	33.3	36.7	13.3				
S. div	26.7	33.3	16.7	26.7	20.0	26.7	23.3	16.7	10.0	6.7	30.0	16.7	16.7	20.0	13.3	30.0	10.0			
P. gra	26.7	30.0	30.0	33.3	20.0	43.3	30.0	63.3	26.7	20.0	23.3	40.0	26.7	16.7	36.7	26.7	23.3	60.0		
A. mem	23.3	23.3	46.7	16.7	23.3	46.7	23.3	20.0	23.3	26.7	33.3	43.3	20.0	20.0	16.7	23.3	20.0	80.0	6.7	
P. pra	23.3	30.0	70.0	40.0	26.7	23.3	30.0	20.0	16.7	23.3	43.3	43.3	23.3	16.7	26.7	26.7	30.0	53.3	36.7	10.0

Legend

Below 25%	
25-50%	
50-75%	
Over 75%	

3.3. Self-assessment of the knowledge

The test showed that there was no significant correlation between error, and the self-assessed knowledge of species identification (r_s = -0.214, n = 30, p = 0.256), or of traditional medicines (r_s = 0.276, n = 30, p = 0.140) (Figure 1).

3.4. Overall response on the image pairs

From the matching task of the image pairs, the mean error response was 25.8% (n = 210, SD = 13.45). The error rates for each pair varied widely (Table 1) although none of the pairs had an error of 0%. The majority of image pairs (n = 122, 58.1%) had an error of less than 25%, while 76 pairs (36.2%) had an error of 25-50%. Only 9 image pairs (4.3%) had an error of 50-75% and 3 image pairs (*Anemarrhena asphodeloides* Bunge and *Curculigo orchioides* Gaertn.; *Prunus armeniaca* L. var. *armeniaca* and *Prunus persica* (L.) Batsch; *Platycodon grandiflorus* (Jacq.) A.DC. and *Astragalus mongholicus* Bunge covering 1.4% of total image pairs had an error over 75%. The image pairs with the highest errors were of the same trade forms i.e. rhizomes, seeds, and roots respectively.

Species abbreviation (trade form): L. gra = *Lophatherum gracile* Brongn.; V. yed = *Viola philippica* var. *philippica*; G. lit = *Glehnia littoralis* (A.Gray) F.Schmidt ex Miq.; A. hen = *Anemarrhena asphodeloides* Bunge; C. orc = *Curculigo orchioides* Gaertn.; L. str = *Ligusticum striatum* DC.; G. ela = *Gastrodia elata* Blume; M. abl = *Morus alba* L.; Batsch; P. arm = *Prunus armeniaca* L. var. *armeniaca*; P. pre = *Prunus persica* (L.) Batsch; A. pub = *Angelica pubescens* Maxim.; D. lon = *Dimocarpus longan* Lour.; L. luc = *Ligustrum lucidum* W.T.Aiton; A. lap = *Arctium lappa* L.; S. fla = *Sophora flavescens* Aiton; G. ura = *Glycyrrhiza uralensis* Fisch. ex DC.; S. div = *Saposhnikovia divaricata* (Turcz. Ex Ledeb.) Schischk.; P. gra = *Platycodon grandiflorus* (Jacq.) A.DC.; A. mem = *Astragalus mongholicus* Bunge; and P. pra = *Peucedanum praeruptorum* Dunn

3.5. Matched- unmatched pairs and single-mixed categories

There was a significant difference ($U_{20,190}$ = 360, p < 0.001) in the error between matched (12.3%, n = 20, SD = 12.09) and unmatched pairs of images (27.3%, n = 190, SD = 13.24). Similarly, the error response rate did not differ between the mixed forms and the same forms ($F_{20,49}$ = 1.52, p = 0.114) (Figure 2). The error was greater for pairs of roots, pairs of leaves, and a combination of roots and stems.

4. Discussion

The COVID-19 pandemic has kept the wildlife trade in the spotlight. This has, in particular, impacted plants because much of the focus has been on animals (i.e. 'plant blindness') due to the possible link between zoonotic transmission and live animal markets, and plants were harvested as a cure for COVID-19 in most regions including as part of government endorsed strategy (Luo et al., 2020; Rastogi et al., 2020; Timoshyna et al., 2020). This is further impacted by the issue of misidentification of plants within the trade and can lead to inaccuracies in the estimation of the nature and volume of trade (Runge et al., 2007; Scharf, 2009).

Here we investigated the issue of misidentification in plant products used in TAMs, using a match-mismatch experiment. We found a mean error in identification of 25.8% (n = 30). This is in line with other recent studies that used a match-mismatch experiment (e.g. Mackay-Smith and Roberts, 2019). Further, as with other studies in both conservation (e.g. Alfino and Roberts, 2019; Austen, 2018) and psychology (e.g. Estudillo and Bindemann, 2014; White et al., 2013; White et al., 2014), unmatched pairs had a significantly higher error than matched pairs.

We found that self-declared expertise in species identification or TAMs did not correlate with the level of error. In other studies that have employed match-mismatch experiments, the relationship between expertise and error varied. Gibbon et al. (2015) studied the mountain bongo antelope, finding only a 5% difference in accuracy between

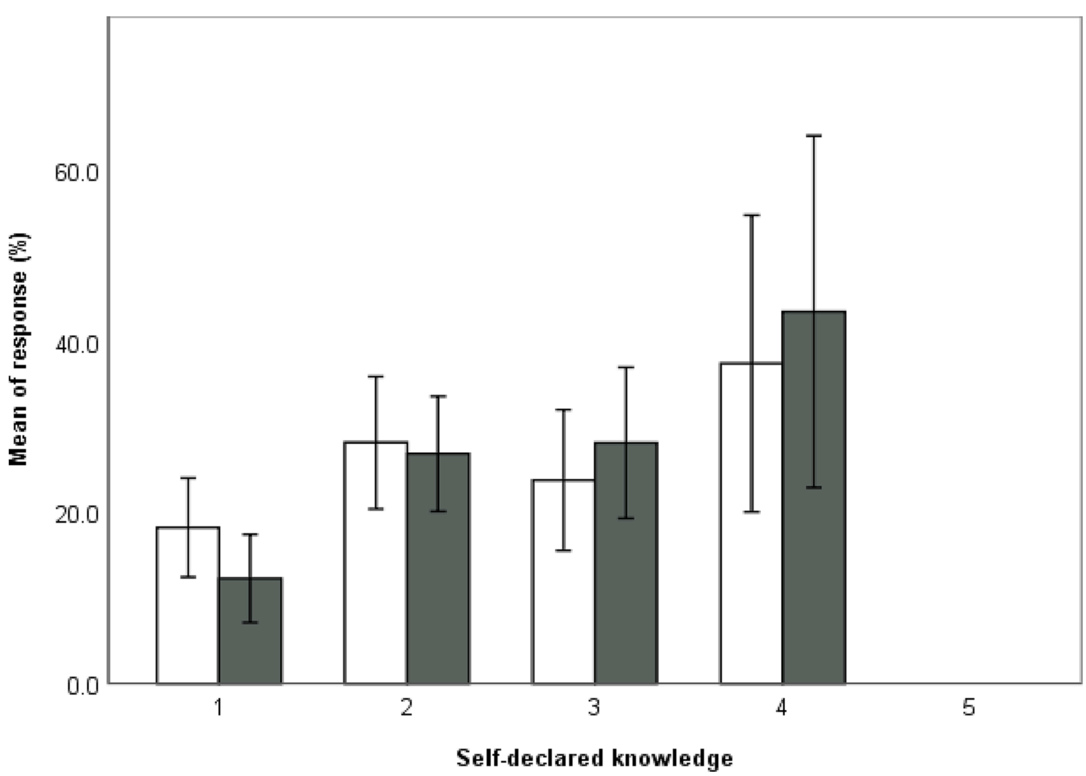

Figure 1. Mean (+/- SE) error rates (%) among the respondents (n = 30) based on their self-assessment of existing knowledge on species identification (white) and traditional medicines (black) on a scale of 1 to 5, 1 being the lowest and 5 the highest.

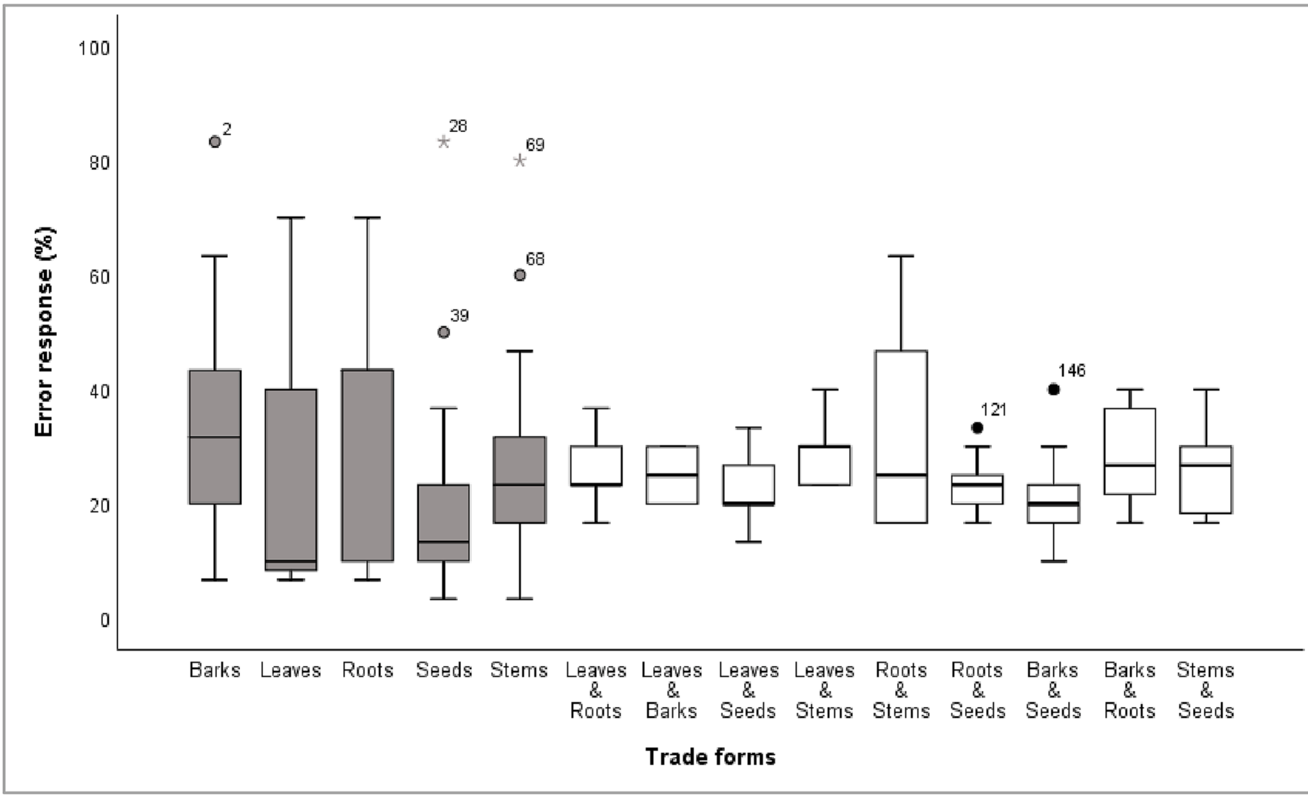

Figure 2. Mean (+/- SE) error rates (%) among different trade forms i.e. same forms (dark) and mixed forms (white)

experts and non-experts. However, Mackay-Smith and Roberts (2019) found a highly significant difference between experts and non-experts when it came to identifying orchids of the genus *Angraecum* from Madagascar. As a result, to improve identification accuracy, instead of just relying on 'experts', it may be a better strategy to triangulate responses with different stakeholders (White et al., 2013), and/or use a wide range of contributors (Swanson et al., 2015), while at the same time improving individual performances by specific training.

Various studies into manual identification have suggested that fatigue impacts performance (e.g., Culverhouse et al., 2003; Gaston and O'Neill, 2004; Masters et al., 2020; Swanson et al., 2016). In visual-cognition studies, the respondent may miss items presented in the scene or overcount (MacLeod et al., 2010). However, based on a study of 210 image pairs representing 20 species, we found no significant difference in the position of the image pair in a sequence and the associated identification error. Further research is required to understand the nature of fatigue in these types of experiments and tasks.

Errors in species identification may be unavoidable, however, knowing where errors are likely to occur can help minimize inaccuracies. While we cannot optimize every aspect of the identification process (Culverhouse et al., 2003; Scharf, 2009), we should aim to understand the circumstances where errors are likely to occur and develop solutions to minimize them (Gibbon et al., 2015). Here we showed that error in identification was heterogeneous between image pairs, with 3 of the 210 image pairs having an error greater than 75%, while over half had an error of less than 25%. In some cases, the image pairs that looked easily identifiable also had greater errors (e.g. *Anemarrhena asphodeloides* Bunge and *Curculigo orchioides* Gaertn.) This suggests that identification errors cannot be generalized or addressed with a blanket approach for all medicinal plants. Future interventions such as species identification training and capacity building of enforcement officials could benefit by highlighting specific groups of species that are likely to result in the greatest levels of error, the extent of trade of concerned taxa, and knowing the parts in trade of specific plant species.

It is important to note that this study looked at the plant parts in their trade forms (e.g., flower, stem parts, rhizome parts, crushed leaves) providing interviewees an opportunity to make comparisons of species presented in the same forms (e.g., leaves and leaves, stem and stem) with species pairs in different forms (e.g., leaves and seeds, stem and flower). When they are processed to form parts like cut pieces of stems, roots, and crushed leaves the plants are difficult to identify. The routine identifications mainly rely on taxonomic units like size, shape, or texture of the specimen, or the presence or absence of specific visual features (MacLeod et al., 2010; Shipman and Boster, 2008). This means that it is very important to understand which species are highly misunderstood and when because misidentified species parts are often used to substitute the other by the traders to transport across the borders. Further, it may be useful to extend this experiment to compare species with similar parts in trade and determine where errors occur the most.

Additionally, for the purpose of trade, the tradable parts are further processed or refined into finished products, including the mixed and processed forms (e.g., a tusk from an elephant, piano keys from tusk). This process of transformation of a species into a desirable form compounds the species identification task (FAO, 2005; Fay, 2015; Roberts and Hinsley, 2020; Timoshyna et al., 2020) although the identification of finished product by enforcement officials is typically based on inspection of labelling or ingredients on the product packaging. Moreover, the traded parts may also be used alongside similar trade parts (e.g., a combination of roots of species A and species B, a combination of roots and stems that are often difficult to distinguish) as found in our study. This presents concerns to plants that are illegally traded as their substitutes mostly in difficult-to-identify forms. For instance, roots of *Saussurea costus,* CITES Appendix I and IUCN RL Critically Endangered species, are found smuggled along with potato trucks (TRAFFIC, 2011). Further, wild-collected plants are often adulterated to enhance potency with unwanted harmful plant species (van Wyk and Prinsloo, 2018). This suggests that the intervention to tackle wildlife trade in terms of training should consider the possible transformations in finished products (Roberts and Hinsley, 2020) as well as the mixing of similar-looking parts in trade.

Misidentification can have serious implications in describing a new species, especially if that species is declining (Beerkircher et al., 2009). Prioritizing species in conservation (e.g., all orchids should not be treated as threatened ones like *Paphiopedilum* spp.; Hinsley et al., 2018). Moreover, misidentified species are easier to transport across international borders (Hinsley and Roberts, 2018), and become an opportunity for generating informal incomes (Nijman, 2010; Pyakurel et al., 2019). The magnitude of cross-border trade in plants is higher than that reported in government records (Robinson and Sinovas, 2018). This suggests an improved trade monitoring effort with an enhanced capacity of customs officials via workshops, testing, and certification programs is required (Shea et al., 2011; UNODC 2012).

This need for training for enforcement officers has been highlighted in different studies (e.g., Gaston and O'Neill, 2004; Phelps and Webb, 2015; Shipman and Boster, 2008) including CITES Wiki Identification Manual database that includes all the resources and manuals to help identify various species of wildlife (CITES, 2023). These recommendations are generic. As a result, they have become very ineffective (Jabin et al., 2019). However, if we apply these findings in real practice it can facilitate the identification process by identifying the areas of potential training, and improving identification tools. This can also help in selecting species for effective improvements in the capacity of para-taxonomists, customs, enforcement officials, and conservation agencies. For example, our study findings suggest three image pairs with the highest identification errors. Of these, *Curculigo orchioides* Gaertn. is extensively traded for its medicinal usage and is facing rapid decline due to commercial trade (Shrestha, Jha, & Kandel, 2011). This suggests the need for prioritizing these species with the highest errors for identification training. Apart from informing the training, this type of study can contribute to minimizing the errors incurred due to misidentification during data collection, monitoring, and other conservation action. Moreover, this study can also incorporate into the trade database (e.g. CITES Trade Database) which faces great uncertainty for even the basic details (Smith et al., 2011); this includes identifying species groups with high identification error rates and noting this in the species trade data as a caveat to keep in mind when drawing conclusions. This work could be extended to understand what level of error in identification could be tolerated and to what extent it affects species conservation and influence of respondent ability to grasp capacity development intervention. Further, we could extend the experiment to compare species with similar parts in trade.

Beyond manual identification, technological solutions are being developed (Culverhouse et al., 2003; Scharf, 2009). Many mobile apps are already in use, such as www.aiplants.net in China with > 1,000,000 users (Ren et al., 2019). These technological interventions help to detect illegally traded wildlife and improve biosecurity in different forms such as automation and digitization (Goodwin et al., 2015; MacLeod et al., 2010), chemical and forensic tools (UNODC 2016), DNA barcoding (Liu et al., 2019), forensic wood anatomy (Wiedenhoeft et al., 2019), and electronic noses (Sutherland et al., 2017). However, these digital tools are costly and have technical and practical barriers (Gaston and O'Neill, 2004). For example, a camera trap is widely used to identify species with the help of a photograph, it still, produces an overwhelming amount of data with varying accuracy (Swanson et al., 2015). Moreover, future research could take advantage to couple these technology-driven identification tools with the findings of experimental studies such as those presented here to facilitate plant species identification and support the evidence-based response to regulate wildlife trade.

5. Conclusions

Understanding the extent and nature of species misidentification, as it relates to the wildlife trade, will help improve the effectiveness of training interventions and the focus of enforcement agencies, custom officers, and other stakeholders. Match-mismatch experiments offer opportunities, not only for research into species misidentification but also for monitoring and evaluation of conservation interventions that involve a species identification component. Finally, in this study involving 20 species and 210 image pairs, we showed that participant fatigue did not appear to impact these results. However, given the diversity of species and their products in trade, more work is needed to determine the limits of match-mismatch experiments regarding participant fatigue and the variety of abilities to match species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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