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From knowledge to healthy colonies: global trends in beekeeper information sources and their usage

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ABSTRACT

Minimising honey bee colony losses requires healthy colonies. An important contributor to maintaining good colony health and vitality is effective colony management, but individual beekeepers vary greatly in their knowledge and application of optimal management practices. Beekeepers become knowledgeable through the acquisition of reliable information, but whilst there are many available information sources for the beekeepers, these vary greatly in quality. The COLOSS B-RAP (Bridging Research and Practice) group, a Core Project of the COLOSS (prevention of honey bee COlony LOSSes) honey bee research association, studies the means for the effective transfer of the latest beekeeping knowledge from scientists and extension workers to practising beekeepers. A purpose-designed questionnaire was used in an international online survey, translated and published by volunteer national coordinators, to collect data on the information sources preferred and most used by the beekeepers, in order to understand the best means for communication and beekeeping education. The study covered 71 countries and received 11,351 responses, mainly from Europe, Asia, North America and Latin America. It was found that knowledge acquisition differed significantly according to various beekeeper characteristics, with the most influential factors being continent, beekeeper age, beekeeping experience and beekeeping education. The results demonstrate the necessity for researchers and beekeeping advisors to diversify their usage of information channels so that a majority of the beekeeping community can access important new bee research results.

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Introduction

Researchers and advisors in agriculture face general challenges in the dissemination of science-based information within agricultural extension, technology adoption and knowledge transfer (Aker, 2011). The same can be said about beekeeping, which in many countries is carried out by hobbyists or "side-line" beekeepers (Chauzat et al., 2013). Managed honey bee (*Apis mellifera*) colony losses are a problem in many countries on different continents (Antúnez et al., 2017; Brodschneider et al., 2018; Chen et al., 2017; Gray et al., 2023; Kulhanek et al., 2017; Pirk et al., 2014; van der Zee et al. 2014; vanEngelsdorp et al., 2012), causing high economic costs for the beekeeping sector, which can financially hinder sustainable beekeeping (Popovska Stojanov et al., 2021). There are many different known drivers for colony losses, including environmental factors, pests and pathogens, beekeeping practices and their interactions (El Agrebi et al., 2022; Goulson et al., 2015; Neumann & Carreck, 2010; Ratnieks & Carreck, 2010; Steinhauer et al., 2018).

Several studies have confirmed that keeping healthy honey bees is associated with the use of best management practice methods and apicultural education (Jacques et al., 2017; Kulhanek et al., 2021; Morawetz et al., 2019; Steinhauer et al., 2021). Furthermore, beekeepers managing small numbers of colonies often experience higher colony loss rates than larger operations (Brodschneider et al., 2018, 2016; Chauzat et al., 2016; Seitz et al., 2015). Special attention is needed in managing honey bees to control the parasitic Varroa mite (*Varroa destructor*), which is now a globally spread and threatening honey bee pest, contributing to honey bee colony losses worldwide (Genersch et al., 2010; Morawetz et al., 2019; Noël et al., 2020; Rosenkranz et al., 2010; Roth et al., 2020; Traynor et al., 2020). However, beekeepers also face other bee health issues depending on which region they live in. These include the Tropilaelaps mite in increasing areas of Asia and now also in Russia and Georgia (Brandorf et al., 2025; Janashia et al., 2024), and foulbrood diseases (*Paenibacillus larvae, Melissococcus plutonius*) in many countries. The complex interventions required in modern beekeeping to maintain healthy bees put beekeepers under great pressure, eventually leading some beekeepers to give up beekeeping (vanEngelsdorp & Meixner, 2010). The work of Cilia (2019) underlines this, based on semi-structured interviews with professional beekeepers in the USA, and stresses that much knowledge and time, effort and financial input is required for successful beekeeping.

Much research is being done to identify established Good Beekeeping Practices (= Best Management Practices) and develop new or optimised colony management strategies (Büchler et al., 2020; Jaffé et al., 2015; Kulhanek et al., 2021; Oberreiter & Brodschneider, 2020; Rivera-Gomis et al. 2019; Sperandio et al., 2019; Steinhauer et al., 2021). It is important to note that colony management preferences may vary between different scale and experience of beekeeper groups, so a one-solution-fits-all dissemination strategy is difficult to identify (Kahane et al., 2022; Underwood et al., 2019). To an even greater extent, beekeepers' profiles, and thus their training needs, vary significantly between different countries and regions (Guiné et al., 2021).

Good Beekeeping Practices need to be communicated or made easily accessible. They also need to be placed into context for beekeepers to understand their importance and to readily implement them in their colony management. Beekeepers vary in their level of beekeeping education, as no formal beekeeping education is required to become a beekeeper. Equally, there are many available sources of information on beekeeping, but these sources are extremely variable in quality and reliability. Mezher et al. (2021) attempted a first exploratory global survey among beekeepers concerning their disease management skills and where they had received technical assistance. According to this, beekeeping associations, self-study from books or websites, beekeeping courses and other beekeepers comprise equally strong and most important sources of information. Another study shows the willingness of beekeepers to receive bee health training from competent veterinarians (De Carolis et al., 2022).

While professional or better educated beekeepers are likely to suffer lower rates of colony loss (Jacques et al., 2017; Oberreiter & Brodschneider, 2020), there are real challenges in communicating the state-of-the-art and best practice to the beekeeper, and to encourage beekeepers to apply these methods in their own beekeeping.

The results presented here arise from the work of the B-RAP (Bridging Research and Practice) group, a Core Project of the COLOSS research association (www.coloss.org). The B-RAP group aims to find ways to better connect beekeepers and honey bee research findings, with the potential to positively impact bee management, and hence equip beekeepers with state-of-the-art beekeeping knowledge (Fabricius Kristiansen et al., 2022).

In this first step we aim to provide quantitative data about the usage frequency of, and the preference for, the various existing information channels in beekeeping. These results will then provide a foundation for understanding the information needs of the beekeeping sector. We hypothesise that usage

frequency and preferences differ by beekeeper origin and beekeeper characteristics as well as differing according to demographics.

Materials and methods

The underlying goal and main strength of the COLOSS association (and thus of its subgroup B-RAP) is a view of bee health issues on a multinational level, as it allows comparison of different systems and trends and hence learning from their particular strengths. Thus, the group decided to approach the question about beekeepers' information sources by conducting an international survey. The concept of this study was devised through discussions of the B-RAP group in conference and workshop sessions, as was the scope of the topics for questions, the means of organising the international data collection and the best timing. The group consists of bee researchers, veterinarians and beekeeping advisors/extensionists. The questions to be asked were drafted and finalised in discussion at the Annual B-RAP Workshop in Toledo, Spain, in February 2020 (Supplement S1). The countries covered by the survey reflected those COLOSS members present, but were principally those involved in the long running COLOSS colony loss surveys.

The survey was implemented using LimeSurvey software (Version 3.26.4 + 210517), which enables multilingual versions of an online questionnaire to be hosted as part of the same survey. The online nature of the survey made it more feasible to collect international data from many countries, despite limitations due to the SARS-CoV-2 pandemic (Dall'Olio et al., 2020), but by definition, it excluded beekeepers not accessing or using the internet. Nonetheless, this was felt to be the best way to reach large numbers of beekeepers internationally, economically and quickly.

National coordinators were recruited for each country, who were either members of the B-RAP group or contacts known to them through COLOSS, who were willing and able to act as a point of contact, prepared to translate the questionnaire as necessary, and also to publicise the survey in their country, for example through their national beekeeping associations and networks, to reach as many beekeepers as possible.

The survey was conducted between May 2020 and February 2021, although none of the participating countries advertised the survey for the whole of this period, but rather for a short period convenient for the local beekeeping community. In total, the survey was translated into 25 languages and was advertised by national coordinators in 29 countries and one region (Latin America; detailed list Supplement 3, Table S3.2).

Focal questions of the analysis

The survey consisted of 30 questions asking about the participants' beekeeping (11 questions), their learning options and dissemination of information (14 questions) and their standard demographic details (5 questions; see the survey form in Supplement S1).

The focus of analysis in this paper is to describe the sources of information used by beekeepers (survey question 17 = Q17) and their preferred sources of information (Q19, multiple choice question).

- Q17: How do you obtain information about beekeeping?
- Q19: Given the opinion, how would you PREFER to get new information about beekeeping?

Both questions presented the beekeeper with 21 different information channels to consider in their response (see Table 1). In Q17, participants were asked to rate these 21 information sources according to how frequently they used them (a 4-level scale: "always", "often", "sometimes", "never"). In Q19, participants were asked to select up to three of the 21 channels that they preferred as sources of their beekeeping information.

These questions were correlated with the demographics of the participating beekeepers: beekeeper type (Q1), years of beekeeping (Q2), beekeeping education (Q3), number of honey bee colonies (Q5), country (Q26), age (Q27), gender (Q28) and formal education (Q30).

To simplify the modelling of Q17, we summarised the 21 information channels into four information categories: 'direct contact', 'group contact', 'web media/audio media' and 'written information' (definitions given in Table 1, where the channels are categorised according to their main way of addressing the beekeeper). The highest rating (of a possible four values for each participant) of all information channels placed into a given category determined the rating given to that information category for that beekeeper. In 57% of cases, more than one information channel had the highest rated category (e.g., if beekeeper X rates the information channels 'beekeeping magazines' and 'beekeeping books' with the frequency 'always', the response of beekeeper X is summarised into an 'always' rating for the information category 'written information').

Table 1. Categorisation of the 21 information channels of the survey into four information categories. Percentage individual: percentage of participants who gave that information channel the highest rating in comparison with the other channels of the particular category. Percentage cumulative: percentage of the cumulative rating of the particular channel and all channels above (in that category). Direct contact: $n = 8{,}518$; group contact: $n = 8{,}626$; web media: $n = 8{,}858$; written information: $n = 9{,}041$.

			Percentage	
Category	Definition	Information channels	individual	cumulative
Direct contact	summarising all information obtained by direct contact with people on a person-to-person basis (e.g. individual meeting/ conversation)	Your mentor	55.4%	55.4%
		Local instructor	54.3%	79.1%
		Beekeeping scientists	42.5%	99.4%
		Beekeeping advisors	37.5%	100.0%
Group contact	based on personal contact in a group setting (e.g. group discussions, talks)	Beekeeping club	77.2%	77.2%
		Networks (with beekeepers, scientists and advisors)	37.5%	92.8%
		National meeting/conference	33.2%	99.5%
		International meeting/conference	12.7%	100.0%
Web media + visual/ audio media	a category containing all sources that can only be obtained by using the internet, and has a focus on visual or audio media	Internet webpages	72.4%	72.4%
		YouTube	54.8%	84.9%
		Social media	49.7%	92.8%
		Video lectures	34.2%	96.2%
		TV programs	21.4%	98.1%
		Webinars	19.2%	99.7%
		Podcasts	8.7%	100.0%
Written information	containing all sources of literature-based information sources, traditionally (but not exclusively) in printed form	Beekeeper magazines	70.5%	70.5%
		Beekeeping books	60.8%	89.4%
		Scientific papers & books	32.2%	93.4%
		Newsletters	25.0%	97.2%
		Popular articles & books	24.4%	99.1%
		Local beekeeping magazines	21.2%	100.0%

Statistics

All statistical analysis was carried out using R 4.1.0 software (R Core Team, 2021). The raw data ($n = 11{,}845$ answers) were cleaned to remove double entries and were checked for implausible answers (for details, see Supplement S2). During this data processing, 4.2% of the entries were deleted, leaving 11,351 entries for analysis. Graphs were produced using the packages 'ggplot' (Wickham et al., 2016) and 'patchwork' (Pedersen, 2022).

For approximately normally distributed data, the descriptive statistics present the mean (denoted M) and standard deviation (SD). For non-normal continuous data, the median, minimum and maximum are shown. Differences in levels of continuous variables between continents were tested using the Kruskal-Wallis test (H statistic). Pairwise Wilcoxon Rank Sum tests were used for testing pairwise differences in cases where the H statistic was significant ($p < 0.05$). Bonferroni correction for adjusting p-values due to multiple testing was applied. Differences between continents in the distribution of categorical variables were tested with Chi-square (χ^2) tests of homogeneity.

For modelling the usage frequency of the four information types, all cases were removed that did not have information on the whole set of independent variables. Ordinal logistic regression models were used to predict the odds of a beekeeper specifying any one response option of a categorical variable (always, often, sometimes, never), using continent and beekeeper characteristics as predictors (package 'MASS', Venables & Ripley, 2002). Forward model selection was used with AIC as the variable selection criterion (selection stops at Δ AIC < 2). To calculate the significance level of the variables, likelihood-ratio tests were calculated using the package 'car' (Fox & Weisberg, 2019). Predictions were computed using marginal means, which means that the non-focal variables were held constant at an average level or value (package 'ggeffects'; Lüdecke, 2018).

For analysing the effect of beekeeper characteristics on the preference of sources, Chi-square (χ^2) tests of homogeneity were used. The analysis concentrated on four beekeeper characteristics with the highest impact during the previously conducted analysis of information channel usage (beekeeper location, training, age and experience) and the five information categories with the highest variance in preference for the respective characteristics (varying between the analysed information channels).

Results

General characteristics of participants

Beekeepers from all over the world participated in this survey ($n = 11{,}351$, Figure 1A). The number of participants was by far the highest within Europe ($n = 9{,}730$), followed by Asia ($n = 780$), North America ($n = 400$) and Latin America ($n = 234$, details in Supplement S3, Table S3.2). Within Europe, most participants were situated in northern or central Europe, with the highest number in Germany ($n = 1{,}581$). Within Asia, most participants were located in Iran ($n = 299$), followed by Turkey ($n = 165$), Taiwan ($n = 140$), Myanmar ($n = 105$) and

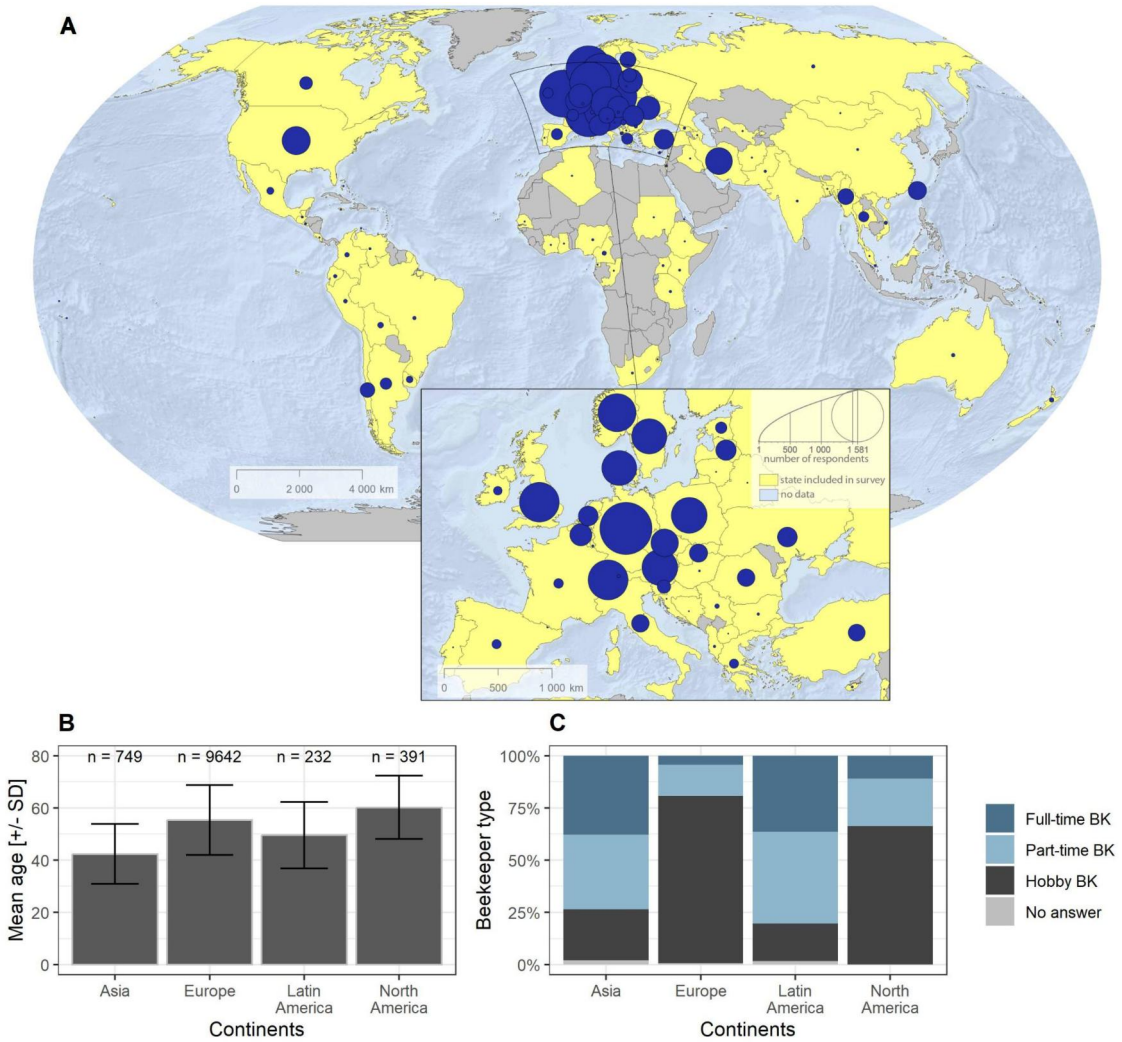

Figure 1. Number of participants (A); distribution of beekeeper age (B); and beekeeper type (C) from Asia, Europe, Latin America and North America. Legend map: yellow = countries with participants, grey = countries without participation; circle size = number of participants per country.

Thailand ($n = 44$) (remaining countries $n \leq 5$). For Latin America most participants were from Chile ($n = 91$), then Argentina ($n = 55$), Mexico ($n = 21$), Uruguay and Bolivia ($n = 14$) (remaining countries $n < 10$). Participants in North America were situated in the USA ($n = 331$) and Canada ($n = 68$). A total of 163 participants did not provide geographic information on their location, so their data were not used in subsequent modelling. Africa and Australia/Oceania were excluded from all further (continent-specific) statistical analysis due to very small sample sizes for both continents (Africa: $n = 28$; Australia/Oceania: $n = 16$). This leaves 11,144 participants from four continents in the analysis.

Participants were on average 55 years old (SD = 17, $n = 11{,}128$), with a minimum of 14 years and a maximum of 99 years. The eight participants with an age above 90 might have made a mistake in their reply; however, their presence in the dataset did not change the trend and significance level of the factor age in the modelling. In total, 75.5% ($n = 8{,}565$) of the participants were male and 22.3% ($n = 2{,}534$) female. Two percent ($n = 228$) of the participants did not provide any information on gender, and the remaining 0.2% were non-binary ($n = 24$). The majority of participants had a university degree (49.6%, $n = 5{,}629$) as their highest level of formal education or had finished secondary school (33.0%, $n = 3{,}747$). Primary school was the highest education level of 5.5% ($n = 621$) of participants, no education of 0.6% ($n = 69$) and the remaining 11.3% of participants ($n = 1{,}285$) did not provide information about their level of education.

Three quarters of all respondents described themselves as hobby beekeepers (73.7%, $n = 8{,}363$), 17.3% were part-time beekeepers ($n = 1{,}969$), and 7.8% were full-time beekeepers ($n = 886$). One percent ($n = 133$) of participants did not answer this question. The number of colonies per beekeeper ranged between 0 and 8,620 (Median = 11.0, $n = 11{,}075$). Thereby, 67 beekeepers said that they owned no colonies, of which 31% were total beginners with 0 years of beekeeping experience, and 94% defined themselves as hobby beekeepers. The

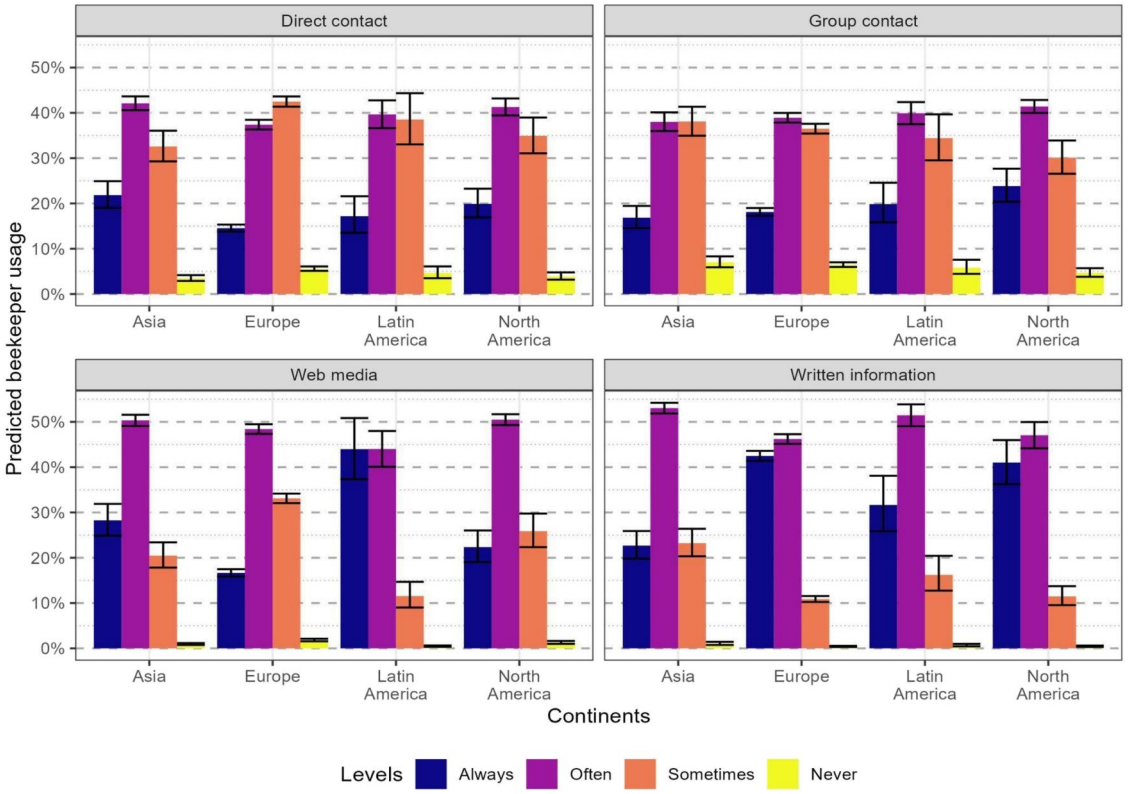

Figure 2. Usage frequency of the four communication types as predicted by the ordinal regression models for the factor 'continent'. Error bars = 95% confidence interval. All other variables are held constant (numeric values = mean, factors = average over the factor levels).

beekeeping types correlated with the number of colonies, with full-time beekeepers having the highest number of colonies (for details, see Supplement S3). The overall median number of participants' years as beekeepers (=beekeeping experience) was 8 years (Min = 0, Max = 73, $n = 10{,}866$). The beekeeping education level 'beginners course' was the most frequent within the sample, followed by 'learning-by-doing' and 'mentorship' (Supplement S3). 'Advanced course' and 'professional qualification in beekeeping' were represented least often within the sample.

All characteristics differed significantly between the four continents analysed (Supplement S3). The most evident differences between continents were in the variables 'beekeeper age' ($H = 706.73$, df = 3, $p < 0.001$, $n = 11{,}014$), 'beekeeper type' ($\chi^2 = 2051.3$, df = 6, $p < 0.001$) and 'beekeeping education' ($\chi^2 = 149.97$, df = 12, $p < 0.001$). Participants were, on average oldest in North America and Europe (Figure 1B). The European and North American subsample was dominated by hobby beekeepers (Europe: 80.1%, $n = 7{,}792$; North America: 66.2%, $n = 265$, Figure 1C), while in Asia, full-time beekeepers were in the majority (37.8%, $n = 295$), followed by part-time (35.8%, $n = 279$). In Latin America, part-time (44.0%, $n = 103$) beekeeping was most frequent, followed by full-time (36.3, $n = 85$).

'Learning-by-doing' was the most common education type in Asia (28.5%) and North America (30.3%; for details, see Supplement S3). 'Beginners course' was most common in Europe (33.8%), whereas 'mentorship' (26.5%) and 'learning by doing' (23.1%) were most common in Latin America. 'Professional qualification in beekeeping' was represented least often within the sample for all continents except for Latin America, where 'advanced course' was stated least often by respondents.

Frequency of use of information sources

In each category, a few dominant information channels have the highest impact on the results and can be seen as the most important channels per category for the beekeepers (Table 1). For example, 70.5% of all participants use beekeeping magazines most frequently in the information category 'written information'. When adding the second most frequently used channel, i.e. beekeeping books, 89.4% of participants are reached by these two most frequently used 'written information' channels. Similarly, nearly all beekeepers can be reached by their most frequently used 'web media' channels, when webpages, YouTube and social media are considered.

Effect of beekeeper location on frequency of use

The participants differed strongly in their information-seeking behaviour by continent (Figure 2). Asian

and Latin-American beekeepers focused their information-seeking strongly on web media channels, while European beekeepers used written information most frequently. American beekeepers had the most diverse information-seeking patterns, using all four media categories at a relatively high frequency.

The ordinal model indicates that the biggest differences between continents were for 'web media' and 'written information'. Information from 'web media' was significantly more frequently used by Asian, Latin American and North American beekeepers than by European beekeepers (χ^2=135.96, df = 3, $p < 0.001$; Table 2). The frequent use of 'web media', especially in Latin America, is also evident in the model predictions (Figure 2, Supplement S4, Table S4.8), as 44% of the Latin American beekeepers are predicted to use it 'always'. They are followed by Asia and North America, for which 28% and 22% of beekeepers are predicted to 'always' use 'web media'. European beekeepers are predicted to use 'web media' least frequently—only 17% are predicted to use them 'always'.

Written information was significantly more frequently used by European and North American beekeepers than by Asian and Latin American beekeepers (χ^2=104.77, df = 3, $p < 0.001$; Table 2). The model prediction of the rating 'always' shows this clearly (Figure 2, Supplement S4, Table S4.7): for Europe and North America, the model predicts that approximately 40% of all beekeepers 'always' use 'written information', compared to 23% and 32% for Asia and Latin America, respectively.

For 'direct contact' and 'group contact', the differences between the continents were significant, but with lower differences between the continents than in the other two information categories (Table 2, direct contact: χ^2=40.86, df = 3, $p < 0.001$; group contact: χ^2=13.24, df = 3, $p = 0.004$, Table 2). This again can be seen when comparing the predictions of the category 'always' (Figure 2, Supplement S4, Tables S4.5, S4.6). For 'direct contact', the category 'always' was predicted for between 15% (European) and 22% (Asian) of beekeepers. For 'group contact', these predicted percentages were between 17% (Asian beekeepers) and 24% (North American beekeepers).

Effect of general characteristics on frequency of use

The set of general characteristics describes the beekeepers' gender, age and education level. These variables had a lower influence on the frequency of use of information sources compared to beekeeper location and beekeeper characteristics, which are considered in the next section (beekeeper type,

Table 2. Model results of the odds ratios (incl. 95% CI) of the four communication types (for details, see Supplement S4). Odds ratio above 1: odds are higher that a beekeeper with the particular factor level uses this communication type more frequently than a beekeeper in the reference category (RC) of the factor or that a beekeeper with higher category values uses this communication type more often than beekeepers with lower values. For odds ratios below 1 the opposite is true (less frequent use than a beekeeper in the RC or less frequent use with a lower numerical value). -- = category excluded from the model during category selection, BK = beekeeping, qualif. = qualification. Direct contact: $n = 8{,}518$, group contact: $n = 8{,}626$, written information: $n = 9{,}041$, web media: $n = 8{,}858$.

	Category	Level	Direct contact	Group contact	Written information	Web media
Beekeeper location	Continents	Asia	1.641 (1.375–1.960)	0.917 (0.767–1.095)	0.397 (0.332–0.476)	1.971 (1.646–2.360)
	RC: Europe	Latin America	1.219 (0.916–1.621)	1.119 (0.849–1.476)	0.627 (0.470–0.837)	3.928 (2.968–5.211)
		North America	1.460 (1.194–1.783)	1.414 (1.154–1.733)	0.942 (0.767–1.157)	1.440 (1.176–1.764)
General characteristics	Gender	Male	0.724 (0.658–0.797)	—	—	1.207 (1.096–1.328)
	RC: female	Non-binary	0.699 (0.302–1.590)	—	—	1.303 (0.530–3.212)
	Age	—	—	1.016 (1.012–1.019)	—	0.986 (0.983–0.990)
	Education	Secondary school	0.888 (0.747–1.056)	0.806 (0.680–0.954)	—	1.162 (0.978–1.382)
	RC: no/primary school	University degree	0.784 (0.661–0.929)	0.656 (0.555–0.774)	—	1.246 (1.051–1.478)
Beekeeping characteristics	Beekeeper type	Part-time BK	1.142 (1.020–1.278)	1.067 (0.955–1.193)	0.672 (0.601–0.752)	1.197 (1.071–1.339)
	RC: hobby BK	Full-time BK	1.369 (1.146–1.635)	1.413 (1.188–1.682)	0.726 (0.607–0.868)	1.070 (0.885–1.293)
	Years experience	—	0.986 (0.982–0.989)	1.014 (1.010–1.018)	1.024 (1.020–1.027)	0.989 (0.986–0.993)
	Number colonies	—	—	—	—	1.000 (0.999–1.000)
	BK education	Mentorship	3.281 (2.890–3.727)	1.388 (1.227–1.570)	1.169 (1.034–1.323)	—
	RC: learning-by-doing	Beginners course	1.452 (1.289–1.636)	1.473 (1.311–1.655)	1.355 (1.208–1.520)	—
		Advanced course	2.268 (1.984–2.593)	2.369 (2.079–2.700)	1.762 (1.543–2.013)	—
		Professional qualif.	2.234 (1.909–2.615)	1.951 (1.675–2.272)	1.773 (1.517–2.073)	—

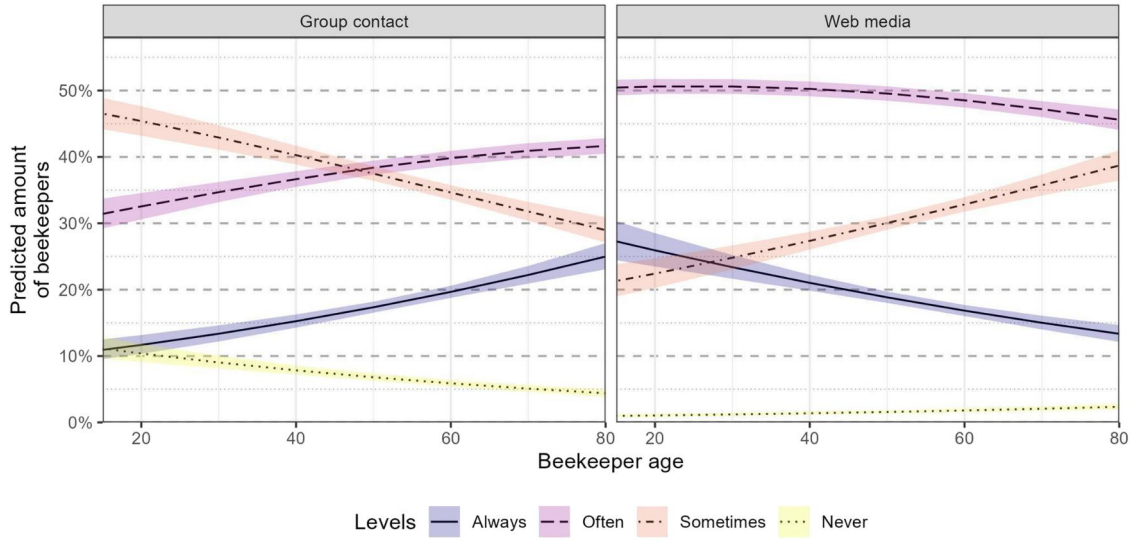

Figure 3. Usage frequency predictions of the two communication types from the ordinal regression models with significance in the factor 'beekeeper age', including the 95% confidence interval (shaded areas). All other variables are held constant (numeric values = mean, factors = average over the factor levels).

beekeeping education, experience, and number of managed colonies).

Of these variables, beekeepers' age had the largest impact on usage frequency. It significantly influenced the usage of the information categories 'group contact' (χ^2=71.10, df = 1, $p < 0.001$; Table 2, Figure 3) and 'web media' (χ^2=56.31, df = 1, $p < 0.001$). With each year of age, the probability of frequently using 'group contact' channels increased, while the probability of using 'web media' decreased. Thus, the model predicts that 13% of thirty-year-old beekeepers, but 22% of seventy-year-old beekeepers, 'always' use 'group contact' information channels. For 'web media', the trend is inverted: the model predicts that 23% of the thirty-year-old beekeepers and 15% of the seventy-year-old beekeepers 'always' use 'web media'.

Gender significantly influenced the frequency of usage of the information categories 'direct contact' (χ^2 = 43.40, df = 2, $p < 0.001$; Table 2) and 'web media' (χ^2=14.84, df = 2, $p < 0.001$), with men using 'web media' and women using 'direct contact' more frequently. However, the differences between the genders were low (see details in Supplement 4).

A higher education level correlated with a lower frequency of use of 'direct contact' channels (χ^2=13.38, df = 2, $p = 0.001$; Table 2, Figure 3) and 'group contact' channels (χ^2=190.62, df = 2, $p < 0.001$; Table 2), but with higher use of 'web media' channels (χ^2=7.70, df = 2, $p = 0.022$). Again, the difference in usage frequency between the levels was low (see details in Supplement 4).

Effect of beekeeper characteristics on frequency of use

The set of beekeeper characteristics describes the beekeeper type, the years of beekeeping experience, the number of honey bee colonies and the level of education in beekeeping (rather than the level of general education).

Among this set of variables, beekeeping education had the strongest influence on usage frequency. It influenced the frequency of use of all information categories except 'web media' (Table 2, 'direct contact': χ^2=414.58, df = 4, $p < 0.001$; 'group contact'; χ^2 = 190.62, df = 4, $p < 0.001$), 'written information': χ^2 = 99.63, df = 4, $p < 0.001$). Beekeepers who had attended advanced courses or who had a professional qualification in beekeeping were active users of 'group contacts' and 'written information'. According to the model, approximately 50% and 25% of these beekeepers 'always' use 'written information' and 'group contact', respectively. For the least active education group, with a learning-by-doing education, beekeepers are predicted to 'always' use 'group contact' in 13% of cases and 'written information' in 34% of cases. For 'direct contact', the most active group are the beekeepers who learned by mentoring (26% 'always'), again in contrast to beekeepers with a learning-by-doing education (9% 'always').

Having many years of experience led to significant increase in usage of 'group contact' (χ^2=48.51, df = 1, $p < 0.001$; Table 2, Figure 4) and 'written information' channels (χ^2=192.08, df = 1, $p < 0.001$), but a significant decrease in usage of 'direct contact' (χ^2=64.49, df = 1, $p < 0.001$) and 'web media' channels (χ^2=30.40, df = 1, $p < 0.001$). The strongest effect of years of experience was seen for the 'written information' channel. The model predicts a 30% increase in using that channel 'always' in the first 30 years of beekeeping (Figure 4, Supplement S4, Table S4.7). A minor increase of 6% is predicted for 'group contact' (Supplement S4, Table S4.6). For

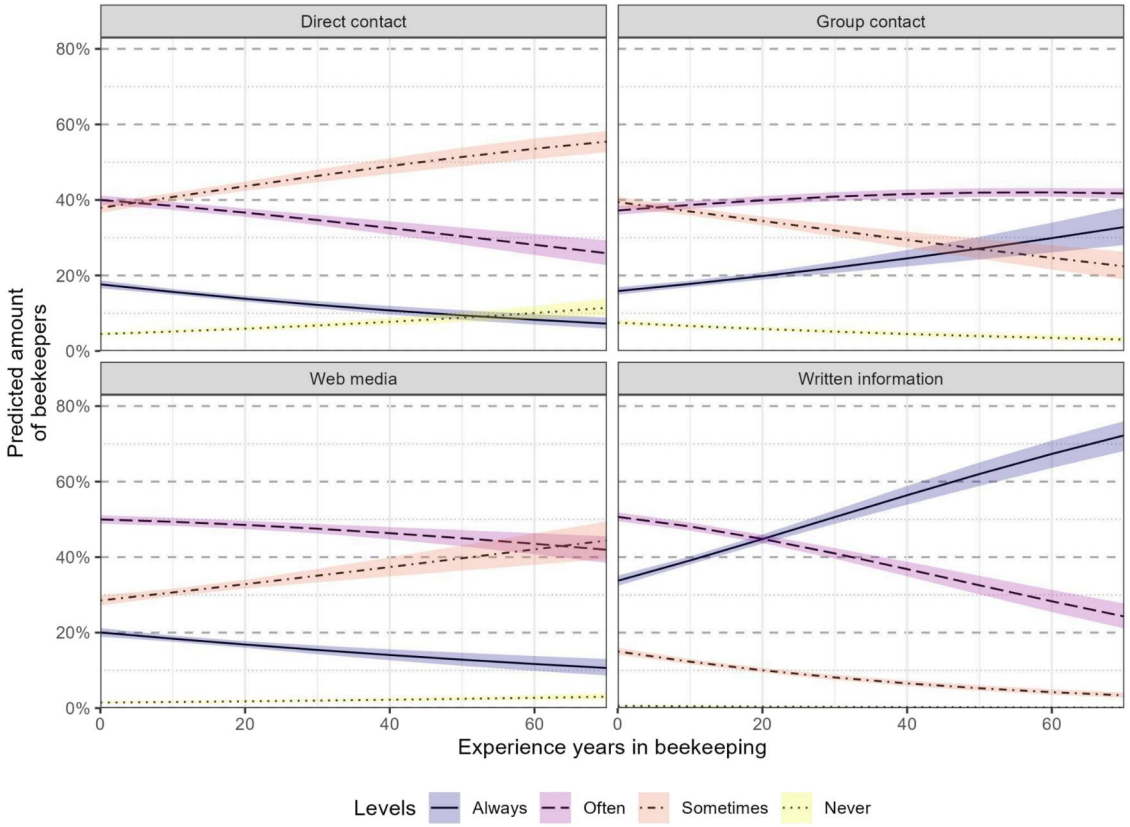

Figure 4. Usage frequency predictions of the four communication types from the ordinal regression models for the factor 'experience years in beekeeping' including the 95% confidence interval (shaded areas). All other variables are held constant (numeric values = mean, factors = average over the factor levels).

both 'web media' and 'direct contact', the predicted percentage 'always' using these information types dropped by 5% for beekeepers with 30 years of experience compared to beekeepers with no experience (Supplement S4, Tables S4.5, S4.8).

The higher their professionalism level, the more frequently beekeepers used 'direct contact' ($\chi^2 = 14.04$, df = 2, $p < 0.001$; Table 2) and 'group contact' channels (χ^2=15.20, df = 2, $p < 0.001$), but the less frequently they used 'written information' ($\chi^2 = 50.98$, df = 2, $p < 0.001$). 'Web media' is most used by part-time beekeepers (χ^2=7.68, df = 2, $p = 0.022$), however, the difference in usage frequency between the professionality levels is low (Supplement S4, Table S4.8).

Numbers of colonies influenced only the usage of 'web media' (χ^2=4,93, df = 1, $p = 0.026$, Table 2). For example, beekeepers with 2,000 colonies are predicted to 'always' use this category half as often as beekeepers with very few colonies (Supplement 4, Table S4.8).

Preferred information sources

In a second question, beekeepers were asked to state how they would prefer to receive information about beekeeping. They could select up to three of 21 different information sources (identical categories as for the question about frequency of use of information sources; see Table 1). The question was answered by 98.9% of all participants ($n = 11{,}351$): the beekeepers selected either one (3.8%), two (5.6%) or three (89.4%) information sources. Eight persons selected between four and six sources because of an incorrectly prepared online survey form (0.1%).

The category 'beekeeping magazines' was by far the most preferred information source (48.5% participants, Supplement S5), followed by 'beekeeping club' (27.8%) and 'beekeeping books' (26.1%). However, as for the question about usage frequency, participant characteristics strongly influenced which information source was preferred. In the following analysis, we focus on four characteristics which already showed high impact in the first analysis on the frequency of usage (Table 2), namely beekeeper location, training, age and experience.

Continent had a significant influence on beekeepers' preferences for information sources (χ^2=1737.6, df = 60, $p < 0.001$; Supplement S5). The highest variation in preference was found for beekeeping magazines and beekeeping clubs (Figure 5); both sources were strongly preferred by European and North American beekeepers, but not by those from Asia and Latin America. Twice as many Latin American beekeepers were interested in being informed *via* beekeeping networks than those from other continents.

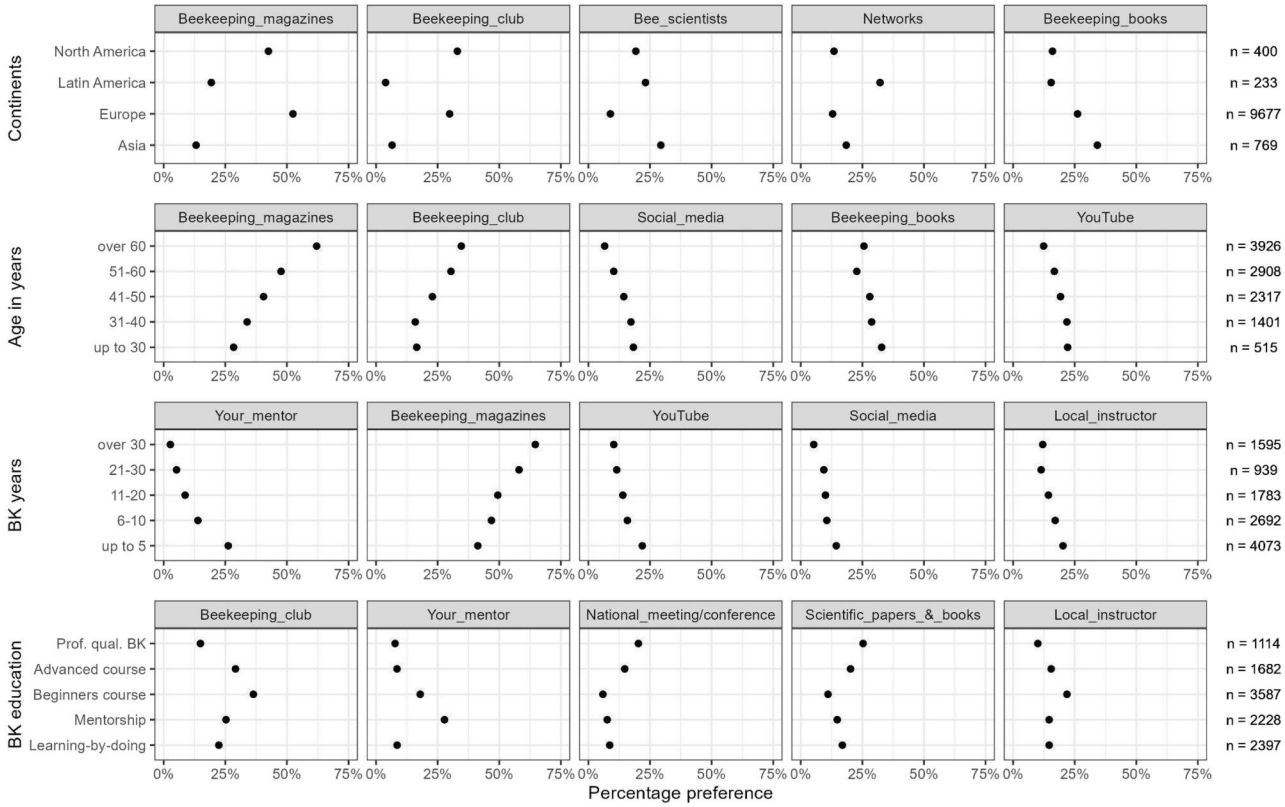

Figure 5. Influence of the four most important factors on beekeeper preference for information sources: Continent, beekeeper age in years, beekeeping experience years (BK years) and Beekeeping education (BK education). For each factor, the five information sources with the highest variation in preference between the factor levels are shown (graph further left: higher variation between the categories).

Respondents differed in their preference for beekeeping sources, depending on their age (χ^2=1186.4, df = 80, $p < 0.001$; Supplement S5) and their beekeeping experience (χ^2=1658.9, df = 80, $p < 0.001$; Supplement S5). The older and more experienced a beekeeper was, the more they preferred beekeeping magazines and the less they preferred social media and YouTube as their information sources (Figure 5). Older beekeepers also showed a strong preference towards being informed through their beekeeping club. Inexperienced beekeepers especially preferred being informed by mentors or local instructors.

Beekeeping education also had a significant influence on the information source preference of beekeepers (χ^2=1752.3, df = 80, $p < 0.001$; Supplement S5). Beekeepers with beginner's course/mentorship education had opposite preferences compared to beekeepers with professional experience; the former preferred being informed by beekeeping clubs or through mentorship, whilst the latter preferred being informed at national conferences or through scientific publications.

Discussion

The present study, for the first time, attempts to analyse and understand the sources of information used and preferred by beekeepers worldwide.

The respondents were mostly male beekeepers of older age with a high education level. This pattern is also typical for previous beekeeping surveys (Duarte Alonso et al., 2021; De Carolis et al., 2022; Engebretson et al., 2022; Gratzer & Brodschneider, 2021; Guiné et al., 2021, 2023; Jacques et al., 2017). The observed gender distribution reflects the beekeeping sector's distribution as experienced by the authors. Participants from Europe and North America are often hobbyists, whilst the Asian and Latin-American datasets, beekeeping is more dominated by (semi-) professional beekeepers. Especially in Asia and Latin America, beekeeping is propagated as a successful tool to increase income and decrease poverty (Hilmi et al., 2011; Jaffé et al., 2015; Schouten & Lloyd, 2019). Thus, the motivation to keep bees may be more economically driven in these continents than in Europe and North America, especially in the case of Latin America, where paid pollination services provide a good income for semi-professional and professional beekeepers (Basualdo et al., 2022). The professional focus of beekeeping in Asian countries is shown in honey production statistics, in which Turkey and Iran, participating in this survey, are the second and third largest honey producers worldwide (FAO, 2021). Europe and North America, on the other hand, do have their highly economically driven beekeeping industries, but also have a

high percentage of hobby beekeepers, who are interested in beekeeping for leisure purposes or have idealistic motivations (Chauzat et al., 2013; Cilia, 2019; Kahane et al., 2022). Thus, the dataset does not reflect the whole of the American/European beekeeping industry but mainly focuses on the hobbyist sector.

Our data illustrate the importance of a well-conceived communication strategy, as a variety of beekeeper characteristics significantly influence the information sources used. Thus, bee scientists and beekeeping advisers have already made a crucial decision when they choose the general communication type that they use to distribute information: whether they write a (popular) article, give a talk, or engage in direct person-to-person contact with beekeepers (Kantar et al., 2023). The most important factors influencing the effectiveness of the communication type are the region in which one communicates, and the age and experience of the beekeepers one wants to reach. Thereby, beekeeping experience is described in terms of years of beekeeping as well as by the level of beekeeping education.

The most prominent factor influencing information-seeking behaviour—both the frequency and the preference—is the continent of origin. The differing beekeepers' preferences reflect the traditions and history of beekeeping and the beekeeping structure of the different continents. Europe and the USA have a long tradition of beekeeping organisations, which have been providing beekeepers with information through printed journals and books, club structures, and spoken lectures since the nineteenth century or even earlier (Crane, 1999; Showler, 1996). Thus, European and North American beekeepers have been used to the easy availability of these long-established sources from the beginning of their beekeeping career and use these frequently, which has also been shown in other studies (Engebretson et al., 2022; Guiné et al., 2023; Maciejovsky et al., 2023; Mezher et al., 2021). Latin American and Asian beekeepers, on the other hand, strongly prefer social media, beekeeping networks and being in direct contact with bee scientists (see also Supplement S5). They began in the middle of the twentieth century to professionalise beekeeping with the Western honey bee, e.g., to focus on modern beekeeping techniques and to increase their colony numbers (Chantawannakul et al., 2018; Crane, 1999; Kandemir, 2003; vanEngelsdorp & Meixner, 2010). Thus, on these continents, the beekeeping networks for knowledge transfer have been established more recently, often within the framework of development projects (Schouten & Lloyd, 2019), and may be less formalised in their structure. New communication technologies, such as mobile phones and the Internet, have several advantages over traditional technologies, especially in developing countries. For example, they allow fast communication and networking in sparsely populated areas, where expert visits and club meetings are very time-consuming to arrange and attend, and they are cheaper than printed products (Aker, 2011). Additionally, they often provide a platform for advertising and marketing the users' own honey bee products (Aker, 2011).

The experience level of beekeepers is an especially important factor for tailoring communication to the needs of the audience, as the required information content may vary widely between beekeepers with a low or high level of beekeeping experience. Therefore, a special communication focus should be aimed at less experienced beekeepers, to increase their professionalism, as this would subsequently decrease the risk of high colony losses (Jacques et al., 2017; Morawetz et al., 2019). New beekeepers use web media and direct contact more often than experienced beekeepers and prefer information sources such as mentors, local instructors, YouTube and social media, which has also been shown by Maciejovsky et al. (2023) for California. To assist these beekeepers in their learning process, there is a great need for high-quality information material on the Internet as this group is especially vulnerable to misinformation available online and over social media (Chowdhury et al., 2023). Furthermore, new beekeepers need regional beekeeping structures which allow a professional level of personal advice or mentoring, as discussed in Fabricius Kristiansen et al. (2024a). A second factor clearly influencing beekeeping professionalism is the general low level of formal education in beekeeping reported throughout the dataset. About 40 to 50% of all participants had never attended a beekeeping course, and another 20% stopped their 'formal education' after a beginner's course (Supplement S2). In many local areas, however, advanced courses are not available. Beekeepers may have many years of beekeeping experience, but their low formal beekeeping education level may lead to crucial gaps in their understanding, which hinder them from becoming more successful and professional beekeepers. They generally use all communication types less frequently than beekeepers with a higher beekeeping education level (but see Table 1: mentorship and 'direct contact'). Additionally, these three low-education groups (learning-by-doing, mentorship, beginners course) differ in their information source preferences, as beekeepers with a 'learning-by-doing' approach may be reached by the Internet and YouTube, while the other two groups prefer personal contacts such as mentorship and beekeeping clubs (Figure 5, Supplement S4). De Carolis et al. (2022)

found that the majority of beekeepers (89.9% in the Americas and 82.8% in Europe) were interested in additional bee health training and, at the same time, were willing to connect with veterinary experts who specialised in bees. It should be noted that beekeepers without any training/with low levels of training may not have been able to access training fitting their needs and interests.

Our results show a snapshot of the different beekeeping cultures in the world, concerning which information channels are used for learning about beekeeping, with written information playing a major role in Europe and North America (the most preferred channel being beekeeping magazines), and online media in Asia or Latin America (the most preferred channel being social media). Nevertheless, the most important recommendation is the necessity to diversify the information channels used, to reach the different types of beekeepers most effectively. Ideally, all information channels should be used—written information, web media, group contact and direct contact—and choosing the channels within the category with the highest level of local preference.

We recommend that advisors and scientists should make a communication plan, so that information transfer, which can be time-consuming, is highly effective, e.g., direct contact is made with influential and active and socially engaged beekeepers, who then transfer the content to their peers, or making group contact at important beekeeping events in the country or region. At the same time, written or recorded information should be provided. In this way, different groups can be reached.

The dataset also gives clear recommendations to the beekeeping sector on how to invest in beekeeping infrastructure. For example, it underlines the necessity of having high-quality beekeeping journals in Europe and North America. Thus, editors of these beekeeping magazines and journals need to be aware of their key role in knowledge transfer and ensure that their content discusses scientifically recommended Good Beekeeping Practices. On the other hand, European and North American bee scientists also need to maintain close contact with the beekeeping journals and beekeeping organisations in their regions and regularly offer content to keep beekeepers updated (Fabricius Kristiansen et al., 2022). This could include directing readers to relevant scientific articles on topics of importance. If the dominance of beekeeping journals is related to the age structure of beekeepers in Europe and North America, and therefore may be fading, follow-up surveys must clarify the situation.

Current trends indicate that Latin-American and Asian scientists and advisors should offer content *via* web media (webpages, YouTube, social media) to reach their beekeepers most effectively. The importance of networking in Latin America should also be considered, as 30% of the beekeepers prefer to use networks of peers, scientists and advisors/extensionists as a source of information. As discussed by Mansourian (2024), social online sharing is an important factor for beekeepers' informal learning possibilities. As young and inexperienced beekeepers use these channels frequently all over the world, the usage of web media is expected to rise in importance in the next few years, independently of location, with the generation shift. Social media communication has its pitfalls, as information is provided in a 'one question - one answer' pattern and seldom provides the context of the question. Thus, one should set a focus to provide scientifically correct but easily understandable context information on the Internet to give web-media-focused beekeepers the possibility of understanding the wider picture.

An important problem associated with use of Internet sources is a high variability in information quality, as any beekeeper can set up and maintain a YouTube channel or moderate a social media group, regardless of their experience level, knowledge, or competence. Depending on their perspective/motivation, beekeepers may even adopt and propagate "Good Beekeeping Practices" which are not officially approved (Kahane et al., 2022). New technologies such as artificial-intelligence-based bee health analysis or beekeeping Apps, both providing management tips, may even increase this problem, as not every algorithm or App may provide useful or reliable information (Morawetz et al., 2024, Fabricius Kristiansen et al., 2024b). However, new technologies may exclude beekeepers without sufficient financial means. There is a need to understand misinformation strategies, reasons for misinformation and its impact, to safeguard the quality of online beekeeping information (Chowdhury et al., 2023). In the case of Latin America, it is necessary to consolidate beekeeping associations to more readily transfer high-quality knowledge and information to them from research institutions and universities.

The results presented here should be interpreted within the framework of the national beekeeping knowledge and innovation systems (B-KIS) of the respective country of interest, as the B-KIS describes the available sources of information in a specific given context (Fabricius Kristiansen et al., 2024a).

An online survey has limitations as a data collection tool, besides its great value as an economically feasible and rapid tool for data collection at a multinational level. The following aspects may therefore have had an impact on validity of the present survey

in terms of representing the whole of the beekeeping community: participation only by beekeepers with an available Internet connection; variation in distribution channels and quality of distribution networks between the different local organisers; a focus on more highly educated beekeepers, due to the academic background of the local organisers; and selection of the countries involved according to the availability of local coordinators in the COLOSS network and others known to them. The high education level of beekeepers participating in online surveys has also previously been found by others (Gratzer & Brodschneider, 2021; Guiné et al., 2021, 2023).

Caution is needed while drawing conclusions from this dataset for all of Asia, as the survey only contained a reasonable number of answers from five Asian countries (Figure 1). Thus, we cannot expect the dataset to cover all trends within Asia, with its diverse societies and beekeeping traditions. Nevertheless, the differences in beekeeping information needs between the continents were pronounced, especially for the usage of 'written information' and 'web media'. Thus, we expect the overall trends to be stable despite the fragmentary data cover for Asia.

Another important factor to keep in mind when interpreting the given data is the possible impact of Covid-19 pandemic restrictions on the beekeepers' information-seeking behaviour. Collection commenced at the beginning of the pandemic and thus gives an impression of information-seeking strategies before the pandemic. The time of social distancing which followed increased the availability of educational material and a multitude of teaching formats on the Internet in the agricultural sector (Bull et al., 2024; Joshi et al., 2022). This may therefore have led to a change in information-seeking behaviour, turning towards the Internet and social media sources. However, socially disadvantaged people and people in regions with low digital infrastructure still had restricted access to the plentifully available online information sources (Nguyen et al., 2021). Therefore, without new data, one must be careful in predicting an increase in use of online information sources for beekeepers of all backgrounds, ages and origins.

Conclusions

In this study, we have revealed intercontinental differences in beekeeping communication approaches, needs and culture in information-seeking concerning beekeeping knowledge. Our results provide information about the future tendencies of beekeepers living in different parts of the world, in terms of the methods they use in searching for knowledge and information. For instance, while beekeepers in Europe use journals and beekeepers' magazines to access information, their interest in digital technology will increase in the near future according to society trends. On the other hand, beekeepers in Asia and Latin America, who are currently using digital technology and social media for information, complain about information pollution on the Internet and the inability to extract correct information, as well as the inability to adapt information coming from countries with better beekeeping practices to their own production systems. Therefore, it is likely that beekeepers on these continents are already experiencing problems that will also soon affect Europe. Measures are required to ensure the transfer of high-quality knowledge to the beekeepers in need of this knowledge. Thus, it is clear that the bridge to be built between beekeepers and scientists, which is the aim of the COLOSS B-RAP group, is not in fact only a single bridge but rather many bridges that should be built using different strategies according to the current situation, the specific local cultural backgrounds, accessibility and also future trends.

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Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the author responsible for the data collection of the respective country/region upon reasonable request.

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