Framework for interrogation of honey authenticity databases (IHAD)

April 2025

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ANNEXES

The four annexes referred to in this framework, are published as separate documents:

Annex 1: Terms of Reference, members and modus operandi of the working group

Annex 2: Appendices 1 to 3 to Part 1

Annex 3: Guidance notes on Appendices 1 to 3

Annex 4: Review Exercise Summary Report.

Summary

Honey is a natural product of foraging bees and has diverse origins, including geographic, botanical, from different bee species and subject to various beekeeping and harvesting practices. Scientific investigation of honey authenticity, which is often questioned, is challenging, necessitating the application of multiple analytical techniques. One of the most powerful approaches is Nuclear Magnetic Resonance (NMR) spectroscopy. However, the use of proprietary databases to interpret NMR results has been identified as a significant barrier to their acceptance. Opacity renders it difficult to check database representativeness and results interpretation. Database owners have offered to open databases to regulatory authorities in cases of dispute. Hence it was deemed expedient to establish an expert working group to investigate and harmonise what database contents and metadata should be disclosed and how it should be appraised.

The working group for the development of a framework for interrogation of honey authenticity databases (IHAD WG) was commissioned by the Department for Environment, Food and Rural Affairs (Defra) and the Laboratory of the Government Chemist (LGC). A WG Chair, Professor Michael Walker, and Secretary, Dr David Hoyland, were appointed and convened a WG membership comprising: -

- The Food Authenticity Centre of Expertise for honey
- Four other internationally recognised honey authenticity analysis laboratories
- Practicing Public Analysts
- A food law barrister/first tier tribunal judge
- Two internationally recognised experts in forensic evaluative reporting and expert statisticians.

Observers from Defra, the Food Standards Agency (FSA), Food Standards Scotland (FSS) and the European Commission Joint Research Centre (JRC) were also present.

More details of the WG membership and terms of reference are in **Error! Reference source not found.**.

The main IHAD WG met six times between October 2023 and December 2024. Specialised sub-groups of the WG met between main meetings. All meetings were virtual and were supplemented by email interchanges. The output of the IHAD WG is this framework document, (FWD).

This document outlines the development of a framework by the IHAD WG to evaluate the fitness-for-purpose of proprietary databases of purportedly genuine honey data used to interpret the results of analytical methods for honey authenticity. The framework describes honey and its analysis for authenticity and adulteration, international Codex Alimentarius standards and EU and UK regulation of honey authenticity. The framework details the optimum approach for examining a database's scope, composition, metadata, representativity, and validation of methods to ensure reliability. Safeguards for database owners are described.

The main findings of the IHAD WG are as follows.

a) Honey authenticity investigation is complex due to the diverse botanical and geographical origins of honey, variations in bee species, and honey harvesting practices.
b) Analytical techniques, especially Nuclear Magnetic Resonance (NMR) spectroscopy, are powerful but face acceptance issues due to proprietary and opaque databases.
c) The key components of the Framework include factors such as database scope, data quality, and metadata that must be scrutinized when assessing database adequacy. Detailed questions for the database owner are listed in three appendices (Annex 2). A review exercise with a database holder

confirmed the feasibility of applying the framework and its appended questions and led to additional guidance to the appendices. (Annex 3).

d) Confidential data transfer and safeguards for proprietary information are essential to balance transparency and intellectual property protection. Infoculture Ltd were invited to present to the WG on the development and implementation of a data trust framework including both technical, legal and organisational components designed to facilitate collaboration among stakeholders in the honey industry.

e) Inspired by its use in forensic science, the framework describes evaluative reporting (ER), a likelihood ratio (LR) based approach to assess the strength of evidence for honey authenticity. Examples of ER application are given including the evaluation of AFGP, (2-acetylfuran-3-glucopyranoside), mannose, caramel and markers in general to help gauge authenticity. Scrutiny of proprietary databases, some containing tens of thousands of data, may provide sufficiently powerful datasets to enable robust ER to be achieved.

f) It is expected that in an evaluative report the strength of the evidence should be described appropriately and the report itself badged as evaluative. If, for whatever reason, ER is not possible or not intended the report must be badged as a technical, investigative or intelligence report as deemed appropriate in the context of the case.

g) The analytical technique, the database used to interpret the results of analysis and the way in which these are reported should all enable reliable, transparent and robust evidence to support decisions in legal, regulatory or other contexts.

h) Science and best practice develop over time. Databases may develop and change over years or decades. The FWD, investigations based on it or findings thereof are not expected to be a counsel of perfection. Rather, the FWD may be used to gauge the appropriateness of an authenticity claim made in any sector of the food industry or as guidance for potential investigators on the examination of allegations made against the authenticity of a food. The FWD may also be considered as an educational tool raising standards for database owners.

i) Methods of analysis must be properly validated prior to being applied to assess honey, and food authenticity in general. It is recommended that, to demonstrate fitness for purpose and for harmonisation of global acceptance, the methods are accredited to an international standard such as ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories. Specific or generic accreditation as appropriate should be considered. Performance characteristics are especially important. Accreditation of opinions, where available, should also be considered.

Conclusions and Recommendations:

Database Interrogation:

Standardised approaches for database scrutiny and representativity evaluations are necessary, recognising that a balance must be struck between a counsel of perfection and the ability to hold to account reported findings and the weight accorded to the evidence.

The WG proposes a set of detailed questions to guide the interrogation process that we commend to any organisation required to adjudicate on honey or any food authenticity based on analytical data interpreted by means of a database of purported genuine samples.

The WG suggests consideration be given to the establishment by an external provider of a trust framework for confidential data transfer. This exercise could be the subject of a future research proposal.

Evaluative Reporting (ER) Implementation:

ER should, where appropriate, be integrated into honey authenticity evaluation and reporting. It is appropriate to apply ER when a competing pair of propositions as to the authenticity of the sample in question can be set by the specific case circumstances or indicated by a regulator or other mandating authority. This is not intended to replace technical, investigative or intelligence reporting. In an evaluative report the strength of the evidence must be described appropriately and the report itself badged as evaluative.

Future Applications:

The framework can be generalised for other food authenticity databases, enhancing global food fraud detection capabilities.

Collaboration and Transparency:

Collaboration with database owners and regulatory bodies is critical for ensuring that the framework's findings are actionable and reliable.

Adoption of non-disclosure agreements (NDAs), peer-reviewed validation and the development of a process for confidential data transfer can increase trust in the process. The latter could be achieved through a further cross-government project aiming to enhance the transparency and reliability of honey authenticity data through collaboration and technological advancement.

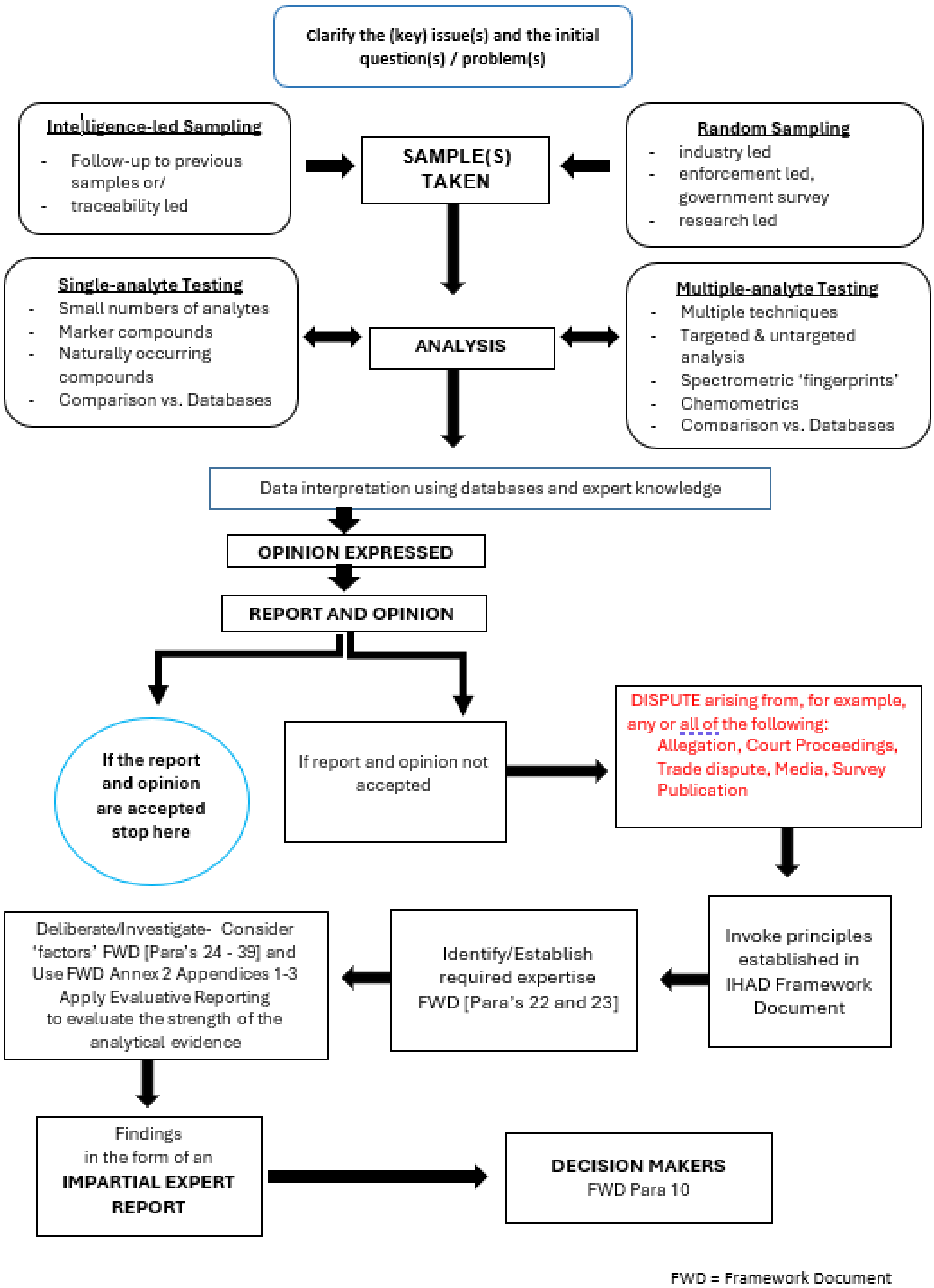
Continuous Improvement:

This framework contributes to continuous improvement in scientific investigation of food authenticity and food fraud by providing tools to interrogate databases of authentic samples and by describing evaluative reporting as a model for quantitative metrics of the weight of evidence to be attributed to results of sampling and analysis. The WG emphasises the need for:

- Ongoing training, on both the framework developed herein for the scrutiny of proprietary databases, and the application of evaluative reporting. These could be achieved through further cross-government (e.g. LGC/DEFRA) Knowledge Transfer, (KT) projects.

- Further research and guidance on evaluative reporting applied to food authenticity.
- Further research, and updates to the framework to adapt to new challenges in food authenticity.
- Knowledge transfer and education of stakeholders, to raise standards in, and harmonise the reporting of, results of analysis so that valid conclusions may be drawn more quickly and robustly by decision makers.

A flow diagram of the basic processes involved in applying the framework proposed by the IHAD WG is presented in Figure 1.



IHAD FRAMEWORK DOCUMENT FLOW DIAGRAM

Figure 1

Introduction

1. Honey is a natural product of foraging bees and has diverse origins, including geographic, botanical, from different bee species and subject to various beekeeping and harvesting practices. Scientific investigation of honey authenticity, which is often questioned, is challenging, necessitating the application of multiple analytical techniques.[1,2] One of the most powerful approaches is Nuclear Magnetic Resonance (NMR) spectroscopy. However, the use of proprietary databases to interpret NMR results has been identified as a significant barrier to their acceptance.[3] Opacity renders it difficult to check database representativeness and results interpretation. Database owners have offered to open databases to regulatory authorities in cases of dispute. Hence it was deemed expedient to establish an expert working group to investigate and harmonise what database contents and metadata should be disclosed and how it should be appraised. The working group aim is therefore to develop a practical framework to establish the expertise required, safeguards for database owners, a process for convening a core group of experts, how their deliberations should be carried out and reported and how the strength of the analytical evidence should be characterised and weighed. For a given question or dispute this practical framework will shape independent scrutiny of proprietary authenticity databases and provide a mechanism to assess their fitness for purpose on a case-by-case basis. Analytical results interpreted by reference to a database that is fit for purpose will give a reliable guide as to the authenticity of a honey. A database that is not fit for purpose will not yield reliable evidence on the authenticity or otherwise of a sample under investigation. The framework we envisage will also enable database owners to evaluate their own content and information curating processes.

2. Additionally, the working group has explored evaluative reporting, an approach well developed in mainstream forensic science, to badge, on a harmonised scale from neutral to very strong, the strength of evidence. The working group output will therefore promote best practice to ensure the authenticity of honey, the assessment of authenticity databases and the reporting of expert opinion about honey analysis. This supports the reliability of information provided by a trader about the derivation of a product or a laboratory analysing honey for authenticity. The terms of reference, members and *modus operandi* of the working group are given in Annex 1.

Scope of this document

3. This framework document is in four parts.
    a) Part 1 introduces ‘honey’, the reasons the work was carried out, discusses honey authenticity and analytical approaches to its investigation. Since opinions on analytical findings often depend on databases a detailed protocol is developed to facilitate interrogation of proprietary databases for their suitability.
    b) Part 2 develops, with worked examples, evaluative reporting, a likelihood ratio based process to evaluate the relative strength of evidence, in this instance analytical findings, in relation to relevant propositions about authenticity.
    c) Part 3 collects conclusions and recommendations.
    d) Part 4 consists of annexes containing details about the Working Group, appendices of detailed questions designed to interrogate a database on a case-by-case basis, guidance notes to their use, a report on a review exercise of the questions, and a glossary.

4. In relation to Part 1, there are several dictionary definitions of the word ‘interrogate’. Definitions include (a) asking questions of (someone)

closely, aggressively, or formally, (b) obtaining data from a computer file, database, storage device, or terminal or (c) asking questions about something as a way of analysing it or finding out more about it.[4] We have drawn nuances from all these definitions. The approach we recommend is an investigative rather than an adversarial exercise. The ultimate value of this document will be realised when it is applied to the evaluation of databases. This may happen for example in relation to an enforcement exercise that results in court proceedings, civil litigation on allegations made about honey authenticity, or decision making about the results of a survey of honey authenticity. In the last example the decision maker may be a regulator or a publisher. In any of these scenarios the output from the interrogation exercise should be an impartial expert report.

5. Regarding Part 2, evaluative reporting (ER) has evolved in mainstream forensic science as a robust statistics-based inferential framework for interpreting complex data in which two opposing (or competing) propositions are considered. These concepts will be described with examples illustrating the appraisal of putative marker compounds of honey adulteration. In this document our focus is on what databases are needed to address the value of the findings in helping to distinguish between the propositions as outlined and how can we use the databases we have. It is crucially important to clarify and prioritise the issues or problems and the initial questions that need to be addressed before setting out on a sampling and analysis exercise and generating a report. This includes the requirements for data and databases.

PART 1 Database interrogation

Honey and its analysis for authenticity and adulteration

6. Honey is a complex natural product, a mixture of sugars and minor and trace components, and is valued as such by consumers. Some honeys from specific origins or with specific properties command premium prices.

7. The global definition of honey stems from the Codex Alimentarius standard[5] which states:

   2.1 Definition
   Honey is the natural sweet substance produced by honeybees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honey comb to ripen and mature.

   2.1.1 Blossom Honey or Nectar Honey is the honey which comes from nectars of plants.

   2.1.2 Honeydew Honey is the honey which comes mainly from excretions of plant sucking insects (Hemiptera) on the living parts of plants or secretions of living parts of plants.

8. The Codex standard includes basic compositional requirements such as maximum moisture content, minimum fructose and glucose content (sum of both), maximum sucrose content, labelling and safety considerations and methods of sampling and analysis. The analytical methods are for the most part straightforward wet chemistry, validated and uncontroversial, necessary to confirm adherence with the compositional standards but unable to deal with sophisticated attempts at

adulteration. Two AOAC methods for the determination of sugars added to honey (authenticity) are referred to in the Codex standard: AOAC 977.20, a liquid chromatographic (LC) method for sugar profile; and AOAC 991.41 an elemental analysis stable carbon isotope ratio mass spectrometric analysis (EA-SCIRMS) for the undeclared presence of cane or corn sugars in honey.

9. Stemming from the Codex standard Article 2 European Directive 2001/110/EC[6] as amended defines honey:

> Directive 2000/13/EC shall apply to the products defined in Annex I, subject to the following conditions:
>
> 1. the term 'honey' shall be applied only to the product defined in Annex I, point 1, and shall be used in trade to designate that product; Annex I (1). Honey is the natural sweet substance produced by *Apis mellifera* bees from the nectar of plants or from secretions of living parts of plants or excretions of plant-sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in honeycombs to ripen and mature. Notice that a specific species of bee (the European or Western honeybee) is included although, worldwide, honey may be collected from other honeybee species. Similar but not identical labelling requirements to those of Codex, and similar compositional criteria are included in the Directive.

Honey is primarily a concentrated aqueous solution of 'invert' sugar (the monosaccharides glucose and fructose) and typically contains a wide range of minor and trace saccharides (see below), amino acids, proteins, organic acids, vitamins, minerals, enzymes, polyphenols and pollen. Some of these arise from honey maturation, others from the bees and some from the foraged plants. Honey composition depends on many factors including the botanical source, geographical origin, species of bee, year and season. Nectar, from which bees predominantly make honey, is composed primarily of water and sugars, such as fructose, glucose, and other oligo- and polysaccharides, and minor constituents, such as pollen, proteins, amino acids, aliphatic acid salts, lipids, and flavouring components. Bees process the collected material with enzymes, including diastase (amylase) and invertase (α-glucosidase). Saccharides include disaccharides (sucrose, maltose etc.) and trisaccharides (melezitose, maltotriose etc.). In certain honeys (mainly honeydew honeys) also oligosaccharides (DP6 to DP9, DP = degree of polymerisation) and polysaccharides (DP10 to DP20) are observed. In the scientific literature lower molecular weight sugars like di- and trisaccharides are sometimes referred to as "oligosaccharides". See for example Megherbi *et al.*, 2009,[7]

10. Figure 2, below, illustrates the wide range of honey authenticity problems that have been identified over many years. In parallel honey is examined for contaminants (e.g. pesticides, heavy metals, veterinary residues), Genetically Modified Organisms (GMO), toxins, fermentation and general microbiology. These latter aspects do not directly concern us in the WG although the presence of contaminants may explain the application of resins to honey to attempt their removal. Any attempt to defraud the honey supply chain risks jeopardising food safety, value for money, business reputation and consumer trust. There have been many allegations of fraud in the honey supply chain, although fewer proven cases however there is no doubt that cases of fraud and sometimes serious fraud amounting to criminality have occurred from time to time in the honey supply chain[8]. The work of the IHAD WG is to enable scrutiny of a critical aspect of honey authenticity, the use of databases, so that claims of adulteration may be investigated, and rebutted or confirmed by an appropriate decision maker. The ‘decision maker’ may be one or more of the following.

a) A laboratory reporting results and opinions. (In some instances, and/or jurisdictions the laboratory is obliged to state whether or not the sample is compliant.)
b) An enforcement or other authority responsible for deciding on formal action against the seller of the product.
c) An enforcement or other authority responsible for deciding on the official publication of the results and/or opinions on the sample.
d) Any entity (e.g. a news media editor) responsible for deciding on the publication of the results and/or opinions on the sample.
e) Any researcher publishing an opinion on the merits or demerits of a technique to appraise food authenticity.
f) A court

11. Honey exhibits a complex composition and natural variation. Both stem from its production by non-domesticated but managed bees that retain their wild foraging nature.[9] There are varying species, differing temporal, climatic and environmental factors, different beekeeping and harvesting practices and post hive processing. It is thus easy to see that challenges exist to analytical methods attempting to determine honey authenticity, particularly in the face of sophisticated adulteration. This has given rise to a great deal of research and proliferation of analytical approaches, see Table 1. There are data gaps and stakeholder differences of opinion on many of the analytical techniques applied to honey. Application of multiple analytical techniques leads to complex reports, opaque to many stakeholders and in some instances containing findings that appear to be contradictory. Moreover, multiple findings, to which different weights of evidence may be given make it difficult to reach a robust overall conclusion on the authenticity or otherwise of a sample. Hence evaluative reporting by the application of likelihood ratios has been proposed[10] and will be examined in Part 2.

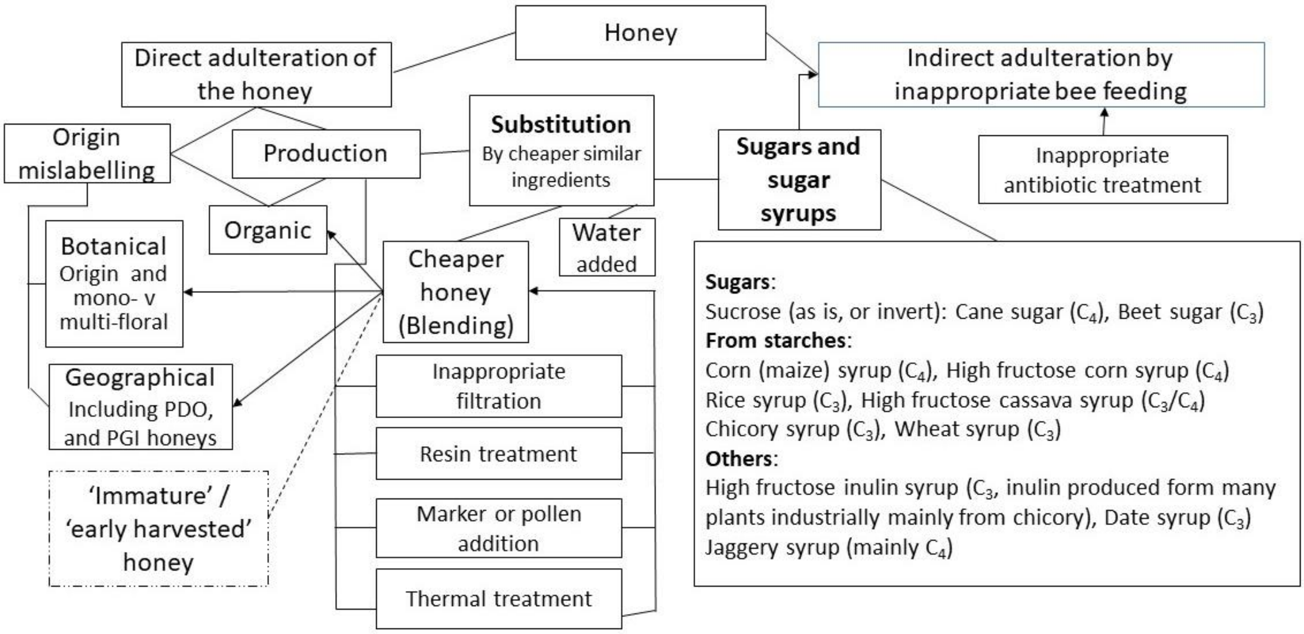


Figure 2: Types of honey adulteration (adapted from Walker *et al*. 2022[1]) Solid lines indicate practices generally regarded as adulteration, a dotted line indicates an area of disagreement.

Table 1: Analytical approaches to honey authentication

Conventional physicochemical analysis, most of which is official and harmonised, and pollen analysis by microscopy.
Isotopic techniques, EA-IRMS and LC-IRMS.
Separation techniques, e.g. sugar profiling by LC or GC.
Spectrometric techniques, including LC-followed by high-resolution mass spectrometry (LC-HRMS), LC-MS/MS for marker detection and GC-MS for aroma profiling.
Spectroscopic techniques, including Fourier transform infrared (FTIR), NIR and NMR.
Trace elements profiling by inductively coupled plasma-mass spectrometry (ICP-MS).
Molecular biology, DNA barcoding and Next Generation Sequencing.
Statistical tools.
Other techniques such as the use of biosensors, electronic tongues and noses, and sensory analysis.
Enzyme profiling/markers, including beta-fructofuranosidase (BFF), beta- and gamma-amylase and 'foreign' alpha-amylase (FAmyP)

12. Methods of analysis must be properly validated prior to being applied to assess honey authenticity. It is recommended that, to demonstrate fitness for purpose and for harmonisation of global acceptance, the methods are accredited to an international standard such as ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories[11]. Performance characteristics such limit of detection (LOD) and limit of quantification (LOQ) are especially important as the detection capabilities (sensitivities) of different techniques (or even instrumentation or methods using the same techniques) used to determine the same analyte e.g. mannose may differ, and this may lead to different interpretations. Thus laboratories should consider accreditation of opinions which although not facile is important since the interpretation of data generated by authenticity methods is often where controversy can arise. Further information on accreditation is available from ILAC, the international organisation for accreditation bodies, https://ilac.org/about-ilac/ and, in the UK, the United Kingdom Accreditation Service (UKAS) https://www.ukas.com/. In some jurisdictions food control laboratories are obliged, even on technical reports, to give opinions. In such circumstances guidance is required, e.g. from the mandating authority, on what analytical performance characteristics (e.g. LOD, LOQ) are appropriate.

13. It is important to note that analytical detection of food fraud/crime in general is rarely straightforward. There are few single unequivocal markers of ‘authentic’ or ‘not authentic’. More often analysis yields binary data (marker(s) present or not, i.e. ≥LOD, v’s <LOD, or concentration ranges of marker(s) which call for informed interpretation. Usually the outcome is that further investigation is required. This is typically a combination of further testing and field investigation such as mass balance, documentary audit or inspection. In addition to two papers by Walker *et al*., 2022[1,10] further information on honey testing is available in reports:

a) A 2015/17 European-wide honey control exercise organised by the European Commission that found a substantial proportion (about 20%) of the 2264 samples taken were non-compliant owing to indications by EA-LC-IRMS of foreign sugars. However, of these a much lower proportion (about 5%) of the samples taken in the UK were non-compliant, owing to incorrect botanical source (4%) or presence of exogenous sugars (1%).[12]
b) A European Commission expert stakeholder seminar of January 2018 that concluded 'direct' adulteration (addition of sugar/syrup) as the most frequent type of fraud. 'Indirect' adulteration is a term for deliberate inappropriate bee feeding with sugars when nectar is naturally available. Bee feeding is widespread and accepted when it is necessary in the absence of nectar and the expert stakeholder seminar recognised that if it does not stop when nectar becomes available it is more likely to be a malpractice rather than fraud.[13]
c) EU coordinated action "From the Hives" (Honey 2021-2022)[14]
d) EU Coordinated action to deter certain fraudulent practices in the honey sector Analytical testing results of imported honey.[15]

Regulation of honey authenticity

14. The EU honey directive 2001/110/EC [6] was implemented in each of the then member states.[16] The Great Britain, (GB) version remains the same since UK exit.[17] EU Directive 2024/1438[18] amended the 2001 honey directive to require mandatory origin labelling for honey. In the EU the countries of origin in honey blends will have to appear on the label in descending order with the percentage share of each origin. EU Member States will have the flexibility to require percentages for the four largest shares only when they account for more than 50% of the blend. The 2024 directive also empowers the Commission to set up an advisory 'honey platform'. The aim is the introduction by the Commission of

harmonised methods of analysis to detect honey adulteration with sugar, a uniform methodology to trace the origin of honey and criteria to ascertain that honey is not overheated when sold to the final consumer. Products which are placed on the market or labelled before 14 June 2026 in accordance with Directive 2001/110/EC[6], may continue to be marketed until the exhaustion of stocks.

15. UK Ministerial policy responsibilities on honey are with the UK Department for Environment, Food & Rural Affairs[19,20] while general food law enforcement policy is with the Food Standards Agency, FSA and Food Standards Scotland, FSS[21]. Enforcement rests with local authorities which may apply a range of civil sanctions including Improvement Notices or Compliance Notices, etc, see FSA Food Law Practice Guidance (England), (Northern Ireland) and (Wales) and FSS Food Law Code of Practice 2019.[22] Failure to comply with these civil sanctions, and UK food law generally, is subject to criminal law.

Databases

16. Laboratory analysis for food fraud can be viewed in two aspects: Targeted analysis – where the target analytes are known, or Untargeted analysis – where 'signals' such as UV-Vis, IR or NMR spectra, or mass spectrometric *m*/*z* data may be known but the exact molecular structure(s) remain to be elucidated. Both approaches are used in honey authenticity analysis. Targeted analysis depends heavily on an exact knowledge of a 'unique' marker or set of markers, their typical concentrations in authentic foods with well characterised variations owing to biological, geographical and temporal influences. Datasets of these variables are of key importance. Untargeted analysis also depends on libraries of structural and other data so that molecular identification is possible, or 'fingerprint' profiles generated. Database software has enabled the setting up

of systems to store, curate and retrieve datasets on food authenticity in general and honey authenticity in particular.

17. A database has been defined in European Directive 96/9/EC on the legal protection of databases as:

> "a collection of independent works, data or other materials arranged in a systematic or methodical way and individually accessible by electronic or other means".[23]

Donarski *et al*.[24] define a food authenticity database as:

> "an organised collection of data, analysed with established protocols acquired from a representative number of authentic samples, with the purpose of defining the natural variability of some particular defined property of a foodstuff."

Donarski *et al*. also discuss what are believed to be the most important considerations which must be addressed, when creating a food authenticity database. Specifically, the areas of database scope, analytical methodology, sampling, collection and storage of data, validation and curation.

18. The UK Government Chemist convened a seminar on honey authenticity in November 2019 on the determination of exogenous sugars by NMR. Fifty-seven stakeholders attended and the outcomes and recommendations have been published[3] As a result of the seminar several studies have been published, including a protocol for the collection of honey reference samples for the construction of honey authenticity databases[25] and a toolkit to support weight of evidence approaches for food authenticity investigation[26].

WG Aims and Considerations

19. The IHAD WG leads on from the 2019 honey seminar[3] where two database owners offered to open databases to regulatory authorities / independent bodies and qualified that the offer only applied in cases of dispute relating to formal enforcement action.

20. Hence the scope of this work is for the WG to form a view on what database contents and metadata should be disclosed and how the examination of a database should be achieved. The WG aim is therefore to develop a practical framework and to establish what expertise is required to do the detailed examination of the composition and representativeness of a database for a particular question or dispute. This will shape any subsequent independent scrutiny of proprietary authenticity databases to assess their fitness for purpose on a case-by-case basis.

Breakpoint

21. A breakpoint in the work after the first meeting was included to allow the WG to discuss if the project was feasible and achievable, and if databases holders might commit to sharing database details. If the work was not able reasonably to continue a short report was envisaged and the project concluded. At the first meeting of the WG it was decided that the work should continue.

What expertise is required to carry out the investigation?

22. The person or (probably preferably) a small group required to carry out the investigation should be independent and include the following expertise:

- Principles of global honey supply chain
- Principles of honey authenticity analysis
- Principles of database interrogation
- External advice on the law and evaluative reporting will likely also be necessary.

23. The governance of the investigative person or group must have regard to the need for independence. This could be modelled on the requirements of professional bodies and should take into account the rules of court on professional reporting. See, for example, Part 35 of the Civil Procedure Rules[27] and Part 19 of the Criminal Procedure Rules[28]. See also the Crown Prosecution Service guidance on expert evidence.[29] Potential conflicts of interest must be disclosed and considered.

Factors to be considered

24. The WG have considered in detail the relevant factors that characterise a fit-for-purpose database although we must be careful to avoid a 'counsel of perfection' which no database could achieve within reasonable resources. The factors below derive from the questions asked by stakeholders at the GC 2019 Honey Seminar[3], from Donarski *et al.*, 2019[24], from the Government Chemist 'Protocol for the Collection of Honey Reference Samples'[25], and from IHAD WG members.
    - Are the factors, individually and collectively, necessary and sufficient to enable a valid opinion to be formed about the authenticity or otherwise of a sample of honey examined by the methods specified and compared with the data in the database?
    - How should the factors be appraised?
    - How should the outcomes of any appraisal be presented, e.g. in court?

- Is the structure and sequence of the factors correct and helpful?
- Although we are concentrating on honey, are our deliberations capable of being made generic for food authenticity databases?

25. The factors to be considered are outlined in the following paragraphs.

Scope of the database

26. A series of questions suggest themselves on the scope of the database:
    - What is the scope of the database and was this defined prior to it being set up? For example, what is the purpose of the database, what type of food, what type of authenticity does it cover (e.g. and see below, geographic, botanical etc. origin).
    - Is one or more end-user identified?
    - At what point in the honey supply chain is the database intended to be used and of value?
    - How much of the scope was set out prior to and during the initial set-up of the database and how much has changed or evolved as the database has grown? This may not have been well defined at the outset, as the database may originally have been started as a ‘look-see’ exercise. The initial scope could well have been narrow, and as work progresses further attributes are typically found for which the database is useful.
    - It is useful to ask what the database is or is not intended for. If it is known the database is not suitable for a certain use that should be mentioned in the scope.
    - How can the claimed scope be assessed as legitimate and viable? What evidence is adduced to support the scope, when and how is the database judged to be suitable to ‘go live’ (e.g. perhaps when the methods are validated).

- Does the database capture the natural range of the variables it holds? How is ‘natural range’ defined? Where the natural range is not covered adequately or at all the scope of the database may be questioned.
- The ‘scope’ question is linked to relevant later sections of the document (representativity, paragraphs 31 to 33).

Composition of database

27. In order to frame and guide looking into a database by those legitimately tasked to do so the types of information the database contains should be known. However, simply asking “what types of information does the database contain?” may leave the database owner struggling to understand what amount of detail their response should give, risking lack of consistency between databases and scenarios. A food authenticity database contains both analytical data derived from reference authentic samples and metadata. A key aspect to understand is the criteria that have been adopted that dictate what samples went into the database as reference samples, which were excluded and what was done to give confidence in their appropriateness. This may be something that applies to different subsets of the data and may have evolved over time. Three appendices explore these questions in more detail. These are presented in Annex 2.

Metadata

28. The concept of metadata, (data about data) has a long history but became an integral part of computer science and information classification in the 1960’s with significant developments in the decades thereafter, described by Sen, 2004[30] alongside which more technical definitions evolved.[31] There is an extensive technical literature on the collection, storage and retrieval of metadata though file management software. Field names, filenames and

software integral to the database management are clearly important to the architecture of a database. What and how metadata are integrally associated with the data is important but is outside the scope of this WG. What we are interested in is assurance of the relevance of the testing data by means of exhibiting correct and sufficient metadata.

29. Donarski *et al*., 2019[24] and the Protocol for the Collection of Honey Reference Samples[25] place great emphasis on metadata and the latter gives comprehensive details of what metadata should be collected to assure traceability of the reference honey samples. Hence it is appropriate to ask how, in broad terms, was the information gathered for the whole database and how many of the principles outlined in the Protocol for the Collection of Honey Reference Samples were followed? This is set out in Appendix 2. Bearing in mind that typical authenticity databases tend to evolve over time it is possible that the metadata may be temporally stratified as to their nature and amount of detail. Means of indicating this are included in Appendix 2 identity and traceability metadata. It is also appropriate to ask if there are any secondary (non-analytical) steps taken (e.g. inspection, audit, mass balance), to assess the authenticity of the sample data loaded to the database?

30. The way in which the database is applied when a honey sample is submitted for appraisal is important. It should be understood if the submitted sample test results are appraised against the whole database or a subset of the data. This depends on the information received by the appraising laboratory. For example, if a sample is submitted as ‘honey’ without any other information it is likely to be appraised against the whole database. Similarly, if a sample is submitted as ‘Blend of EU and non-EU honey’ should the whole database be deployed or only a subset of such blended honeys? Again, if a sample is submitted as a purported Mānuka honey should it be appraised against only a subset of

reference Mānuka honeys in the database? Does the laboratory take a staged approach to the interrogation of the database and on what basis is that undertaken?

Representativity of the database

31. What steps are taken to assure the representativity of the database in terms of the botanical source, geographical origin, species of bee, year and season, and processing (including bulking and/or blending)? What steps were taken to assure that ranges of natural variation are captured in the database? Is the global honey production density reflected in the database (if required by defined database scope, i.e. purporting to represent global honey)? Is the database curated and reviewed regularly?

32. How are data analysis, interpretation of results carried out? Note: detailed discussion of the merits and demerits of individual methods employed are left to a subsequent working group.

33. How are the results of analysis and interpretation reported? (See paragraphs 77 and 78 on Reporting).

The Appendices (Annex 2)

34. Appendix 1 contains 20 questions (four preliminary questions and 16 ‘subject’ questions) on the quality assurance of the database, reporting and reference data set. These structured questions focus on a range of topics. These include database scope and its evolution, interpretation, whether a staged approach is used, how reference sample selection is justified, and whether fixed algorithms assist interpretation. There are questions on reporting, how reports are labelled (e.g., evaluative, investigative, technical), whether detailed data is provided,

and if the report signer is qualified. Database maintenance and curation are covered.

35. Appendix 2 contains five sets of questions containing 20, 22, 16, 16 and 15 questions respectively, a total of 89 questions on the reference sample traceability metadata.

36. Appendix 3 contains 41 questions on reference sample analytical metadata.

Review exercise

37. A review exercise was carried out with the cooperation of a database owner. This was to gauge the feasibility of applying the framework and its appended questions. This would allow the proposed questions to be reviewed in more detail by a database holder than had been possible during the WG meetings. Although the fundamentals and applicability of the framework document itself would not be challenged the review exercise was considered suitable within the constraints of time and funding. A breakpoint was incorporated into the IHAD WG workplan pending the completion of the review exercise. The review consisted of a series of meetings with a database holder during which the appendices questions were assessed. The majority of questions were found to be sensible and capable of being answered relatively easily. A small percentage of the questions required more explanation properly to answer. This was addressed by production of guidance (Annex 3). A summary of the review exercise and its findings can be found in Annex 4 Thus the breakpoint was not triggered and work on the framework was able to continue.

Confidential data transfer

38. Having decided on what to explore in a database to assess its suitability thought must be given to how the process should be undertaken. The aim should be to

facilitate the mechanics of a potentially large amount of data transfer and the need to protect, as far as reasonably possible, the intellectual property of the database owner.

39. The WG identified three organisations with experience of confidential data transfer. When approached only one of the organisations, Infoculture Ltd (https://www.infoculture-lab.com/), responded. Infoculture Ltd had previously prepared a feasibility study for FSA on collaborative data sharing with regard to honey authenticity[32] and has published on the topic[33, 34, 35]. Infoculture Ltd was invited to present an overview of a proposed approach to confidential data sharing to meeting five of the WG and answered questions from the WG. Infoculture emphasised the development and implementation of a data trust framework including both technical and organisational components designed to facilitate collaboration among stakeholders in the honey industry. The trust framework would also include legal agreements, roles, responsibilities, and a business model. This exercise could be the subject of a future research proposal. The deliverables might include:

   a) A Trustworthy Data Sharing Club Design and governance model to ensure secure and reliable data exchange.
   b) An Interim Report including an operational and business plan.
   c) A Trust Framework Implementation pilot system.
   d) A Complete System Qualification including a fully operational system contingent on the success of the pilot.
   e) A Final Report containing comprehensive documentation of the implemented solution.

40. It is also worth remembering that disclosure of evidence is a well-established practice in law. In UK law, disclosure is the process of providing relevant

information to the other party in a legal dispute. The purpose is to make sure that both or all parties know of all documents that have a bearing on the case. The word “document” means any form of recorded information and includes pictures, emails, mobile phone texts, social networking messages or video-clips. Hence it is reasonable to assume that disclosure extends to data held in a database so long as it is relevant. In criminal cases the defence must be provided with copies or access to any material that could help their case or weaken the prosecution's case. In civil litigation each party must disclose documents that are relevant to the dispute, including documents that support or undermine their case. In investigations a disclosure order can require the provision of information or documents if they have information that's relevant to the investigation. The disclosure process is intended to ensure that both parties have an early opportunity to share relevant evidence. A document does not need to be produced if it's private or privileged, such as legal advice or letters to a solicitor. If a party objects to producing a document, they can explain why and either party can apply to the court to rule on whether the document must be produced. In addition, some aspects of the information may be redacted.[36] It should be remembered that any confidentiality requirement has limits and is generally subject to a disclaimer clause along the lines of 'save where required by law to disclose'.

PART 2 Evaluative Reporting

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Evaluative reporting

41. Evaluative reporting, ER, is an approach that enables an investigator or laboratory to assign a quantitative metric as an expression of the strength of evidence given a pair of propositions about the sample(s) under investigation. This links to the framework for assessment of databases in two ways: (a) The information in a reliable database feeds into the evaluative exercise that assists a decision maker to reach a conclusion about the authenticity of the honey under consideration; (b) ER also allows us to gauge the adequacy of the contents of a database by enabling an assessment of the amount of data in the database relevant to the pair of propositions about the honey under investigation. These concepts will be described with examples illustrating the appraisal of putative markers of honey adulteration. The conclusions arrived at on the evidential strength of the markers may be indicative, but it is not within the scope of this work to be definitive as to their evidential strength. That will be a task for users of the approach in a live investigation.

42. ER builds on previous guidance, the European Food Safety Authority, EFSA, guidance on the use of weight of evidence and Defra and the Government Chemist, GC, toolkit on the appraisal of the weight of evidence. EFSA guidance[37] is focused on chemical risk assessment and a process in which evidence is integrated to determine the relative support for possible answers to a question. The guidance deals with both qualitative and quantitative approaches and identifies reliability, relevance and consistency as three basic considerations. The Defra and GC toolkit[26] addresses the weight of evidence attributable to complex multifaceted authenticity data. The toolkit sets out a structured approach for collating and weighing evidence covering both analytical and documentary review/records audit evidence. The toolkit lists key considerations for each stage, takes a qualitative approach and provides

examples of what could be considered as weak and strong evidence and includes case-studies. It draws attention to Organisation for Economic Co-operation and Development, OECD, principles on weight of evidence that suggest generating a hypothesis and possible alternative hypotheses as a starting point which involves a clear formulation and statement of the problem for which evidence is needed. In ER the starting point is also assessment of the requirements for data and clear hypotheses before generating a report on the authenticity of a sample of food. ER drives a systematic approach to weighing authenticity evidence and provides a generally agreed scale linking quantitative data to verbal descriptors of the strength of the evidence. Applying approaches to problems in food authenticity derived from mainstream forensic science was described in 2019[38] and ER was proposed in 2022[10].

43. ER has evolved in mainstream forensic science as a robust statistics-based inferential framework for interpreting complex data in which two opposing (or competing) propositions are considered. Conventionally, given the origin of the concept, the twin propositions are typically viewed as being advanced respectively by the prosecution and the defence. ER then involves assignment of a likelihood ratio (LR) which is the probability of the evidence if the prosecution proposition is true divided by the probability of the evidence if the defence proposition is true and takes into account task-relevant information (see paragraph 51 for further details). These concepts will be described below with examples relevant to honey authenticity and for further background please see European Network of Forensic Science Institutes, ENFSI 2015, evaluative reporting guidance[39] and Royal Society, 2020, The use of statistics in legal proceedings, a primer for courts[40].

44. Hicks *et al*., 2015[41] (citing Evett *et al*., 2000[42]) have described how the two opposing propositions should be framed, and emphasised that:

a) Evaluation of the analytical findings takes place within a framework of circumstances. To clarify the issue that analysis can help with the circumstances must be understood. Thus the probabilities are 'conditional', in that they depend on what we know, what we are told and what we assume, i.e. they are case-specific. Context driven interpretation is also essential in food authenticity appraisal.
b) The role of the expert and the role of the decision maker are separate; scientists ought to give their assessment on the results and not on the propositions.
c) Propositions are mutually exclusive and exhaustive in the context of the matter in hand, the propositions cannot both be true and there must be no other propositions that, at the time of the evaluation, appear to be relevant.
d) Propositions are statements that are either true or false, and that can be affirmed or denied (Anderson *et al*. 2005)[43]. Propositions should be formulated against a background of information and assumptions. Moreover, they should be amenable to a reasoned assignment of credibility by a decision maker and be useable for rational inference, i.e. testable in a logical sense.
e) Propositions are about 'causes' (i.e., target events that lead to particular findings), hence analytical results should not be included in propositions. Although, if the results allow no discrimination or if their value can be assigned without expert knowledge, then including these data in propositions will have no impact and is thus acceptable.
f) Propositions should not be findings-led, i.e. the formulation of propositions should be made before evaluating the results against a potential cause.
g) The probability of the results must not be confused with the probability of the propositions. Thus a high LR corresponds to a situation in which

it is much more likely that the observed evidence would occur if the 'prosecution' proposition were true rather than the 'defence' proposition. This represents strong evidence in support of the prosecution proposition, but it is important to note that a high LR alone says nothing about the probability that the prosecution proposition is actually true, (a decision for the decision maker (e.g. the court) to take on *all* the evidence before it). This is a common error and will be emphasised in the discussion below.

h) It is important to consider propositions before examining the evidence, but it may be necessary to refine them. This could be the case if further information becomes available or in the light of a detailed consideration of the information about the sample and the analysis carried out. The process of generating propositions may involve the creation and critical evaluation of 'explanations' that may explain the evidence, or aspects of it, but do not enable the weight of the evidence to be determined. Further information is available in Evett *et al*., 2000[42].

45. Before embarking on a more detailed consideration of ER it is useful to discuss some terms used in food authenticity evaluation. Hill Hassall, 1876[44] defined adulteration as:

> "The intentional addition … of any substance(s) not acknowledged in the name … for purposes of gain, deception or concealment".

The European Committee for Standardization (CEN) CEN/TC 460 - Food Authenticity has a standard[45] on concepts, terms, and definitions in food authenticity. For example, the CEN proposed definition of 'adulteration' is:

> "intentionally adding an undeclared ingredient to the food product, or substituting a declared ingredient with another ingredient, or increasing the volume of a liquid product by dilution."

Adding sugar syrup to honey would be classed as adulteration. The absence of adulteration can be termed as 'genuine'. Elahi and Wilkes (2023)[46], note

> 'adulteration' is defined as a category of food crime meaning "reducing the quality of a food product through the inclusion of a foreign substance, with the intention either to make production costs lower, or apparent quality higher".

46. The UK Food Safety Act 1990[47] (section 14) makes it an offence to sell food that is not of the nature, substance, or quality that the purchaser expects. Sugar syrup sold as 'honey' is a 'not of the nature' demanded, honey containing sugar syrup may be 'not of the nature' or 'not of the substance' demanded depending on the quantities involved. Quality issues with a sample of honey encompasses many aspects.

47. The terms 'compliant' and 'non-compliant' generally mean not complying with a requirement of legislation, e.g. mycotoxins, pesticides, or metals in excess of prescribed limits. Other examples include products deficient of legislatively required limits, e.g. the amount of meat or a named species in meat products, the level of alcohol in prescribed spirit drinks, diastase activity in honey and so on.

48. If a sample is said to be 'untypical', reference must be made to the comparison, i.e. what it is 'untypical of', and if the sample is alleged to be misdescribed it must be made clear in what regard it is not correctly described.

49. In view of the above we suggest the propositions regarding a honey sample should be one of the following pairs:

a) 'The sample is adulterated' or 'The sample is genuine'.
b) 'The sample does not belong to a particular category' or 'The sample does belong to a particular category'.
c) 'The sample is misdescribed' or 'The sample is correctly described'.

50. Additional context should be given by way of conditioning information, e.g. relevant details of the honey labelling, where in the supply chain a sample under investigation was taken, and so on. It should be noted that one of the main requirements of the Directive 2001/110/EC[6], the 'honey directive' (Annex II) is that:

> "When placed on the market as honey or used in any product intended for human consumption, honey shall not have added to it any food ingredient, including food additives, nor shall any other additions be made other than honey."

In considering questions of 'adulterated' or 'genuine' it is appropriate to bear this key compositional requirement in mind rather than other facets of Directive 2001/110/EC such as fructose, glucose or sucrose content, moisture, diastase activity or HMF concentration. These compositional criteria are given statutory thresholds in the Directive and are dealt with by technical, rather than evaluative, reports that, if an opinion is required, may state, subject to adequate method performance characteristics, whether the sample is compliant or not with a particular requirement of the Directive.

51. The attraction of evaluative reporting is its ability to assign a quantitative metric as an expression of the strength of evidence given the pair of propositions of interest. This is achieved by assigning a likelihood ratio. The likelihood ratio is defined as the ratio of the two conditional probabilities discussed above: (a) the probability of observing the evidence given that one proposition is true and given the conditioning information; and (b) the probability of observing the

findings given that the other proposition is true and given the conditioning information. This can be set out as shown in equation (i)

$$\mathrm{LR} = \frac{\Pr(E \mid H_p, I)}{\Pr(E \mid H_d, I)} \quad \text{(i)}$$

where the symbols represent:

Pr: Probability
E : Evidence
| : The vertical bar is read as 'given'
I : Information (the conditioning information)
H : Proposition
Hp and *Hd* represent the two propositions ('prosecution' and 'defence').

For (bio)chemical markers of adulteration, in effect in equation (i) the numerator can be informed by the relative frequency at which the marker is found in adulterated honey. The denominator, on the other hand, can be informed by the relative frequency at which the marker is found in genuine honey.

52. Probability can be written as a fraction, a percentage or a decimal numeral. For example the probability of getting 'tails' when a coin is tossed is a 1 in 2 chance, which can be expressed as ½, 50% or 0.5.[48] For any event or issue, the probability of its occurrence can be expressed as a numerical value between 0 and 1 inclusive. Only impossible events can realistically be assigned a probability of zero (Cromwell's rule)[49].

53. The probability Pr, of obtaining the evidence *E* is conditional on each proposition together with any information available. A high LR corresponds to a situation in which it is much more likely that the observed finding (e.g. analytical result(s), NMR profile, isotopic ratio … the 'evidence' *E*) would occur if *Hp* were true rather than *Hd*. This represents strong evidence in support of *Hp*, though it is important to note that a high LR alone says nothing about the probability that *Hp* is actually true, (an assessment for the court or decision

maker to make on all the evidence before it). Propositions can be differentiated within a hierarchy of ‘Source’ (e.g. issues of authenticity), ‘Activity’ (e.g. alleged action by a third party to adulterate the honey) and ‘Offence’ (which includes questions of intent). This work is confined to source propositions. The purpose is to assess the probability of the evidence if the honey is adulterated over the probability of the evidence if the honey is genuine. The pair of propositions must be mutually exclusive, exhaustive in the context of the case and avoid ambiguities between ‘source’ and other hierarchy levels. Avoiding such ambiguity drives appropriate rigour in dealing with the value of the evidence.

54. ER enriches decision making on foot of analytical data because there is already a generally agreed narrative or verbal scale available, Table 2, relating the likelihood ratio to a verbal expression or statement of the strength of evidence.[50] The verbal scale is an aid to conveying the order of magnitude however the numerical value of the LR is of primary relevance.

Table 2: Example of forensic verbal scale

Likelihood Ratio, LR (order of magnitude whole integers*)	Verbal equivalent (two options of phrasing are suggested) (Source: ENFSI Guideline for Evaluative Reporting in Forensic Science[39])
1	The findings do not support one proposition over the other. The findings provide no assistance in addressing the issue.
2 < LR ≤ 10	The findings provide weak support** for the first proposition relative to the alternative. The findings are slightly more probable given one proposition relative to the other
10 < LR ≤ 100	The findings provide moderate support for the first proposition rather than the alternative The findings are more probable given … proposition ... than proposition...
100 < LR ≤ 1000	The findings provide moderately strong support for the first proposition rather than the alternative The findings are appreciably more probable given… proposition ... than proposition...
1000 < LR ≤ 10000	The findings provide strong support for the first proposition rather than the alternative The findings are much more probable given … proposition ... than proposition...
10000 < LR LR ≤ 1,000,0000	The findings provide very strong support for the first proposition rather than the alternative The findings …are far more probable given … proposition ... than proposition...

Notes to Table 2
* Likelihood ratios corresponding to the inverse (1/X) of these values (X) will express the degree of support for the specified alternative compared to the first proposition.

** Practitioners or their reports should avoid conveying the impression that a statement of the kind: "the forensic findings provide weak support for the first proposition compared to the alternative" means that the findings provide (strong) support for the stated alternative. It just means that the findings are up to 10 times more probable if the first proposition is true than if the stated alternative is true. This is also the reason why the alternative should be explicitly stated. In cases where the reader could be misled as described above, practitioners must add additional comments. It is also important to remember that ranges of likelihood ratio in the table above are indicative and should be seen as a continuum of expression of strength of support. It is obviously understood that a likelihood ratio of 999 is only trivially different in its overall impact from one of 1001. Finally, LR should be rounded to integers following the usual rules including a rule to deal with '5', such as 'rounding up'.

55. It is important to avoid the error of advocating a high probability for the proposition given the evidence when the probability of the evidence given the proposition is high. This error is variously termed the 'inversion fallacy', 'transposing the conditional' or 'the prosecutor's fallacy'. Evett (1995)[51] gave a famous example, concerning cows and four-legged animals generally. that we might adapt. The probability, Pr, that a flying insect has four wings if it is a bee is 1. But stating that the probability that a flying insect is a bee if it has four wings is 1 is clearly erroneous. Similarly, the probability that the main sugars in a sweet liquid are fructose and glucose if it is honey is 1. Stating that the probability that a sweet liquid is honey if the main sugars in it are fructose and glucose is 1 is clearly wrong as there are sweet liquids, sugar syrups, in which the main sugars are fructose and glucose. These, of course, are not honey. More formally, for the probability that the main sugars are fructose and glucose, E, given that the sweet liquid is honey, H_1 we can write $\Pr(E \mid H_1) = 1$. But, writing $\Pr(H_1 \mid E) = 1$ is wrong as it transposes the conditional (proposition) and the evidence.

56. Properly carried out ER provides a more logical and equitable means of assessing analytical findings and enables reports to be drafted without the use

of vague expressions such as 'is consistent with', 'strongly suggests' or 'suspicious of … [an allegation]'. How should we go about using ER? The steps, adapted from the ENSFI guidance on ER[39], should include:

a) Identify the key issue(s) by considering all available, relevant information and, where necessary, requesting additional information in discussion with the relevant authority requesting the analysis and report.
b) Choose an appropriate pair of propositions (see paragraphs 49 and 50).
c) Assess the analytical approach(s) required and the dataset(s) needed to interpret the results of analysis.
d) Assess if an evaluative report is appropriate and can be produced.
    i. If no appropriate pair of propositions can be formulated, then no evaluative report can be produced. The laboratory could provide an intelligence, an investigative or a technical report as deemed appropriate in the context of the case, but it must be badged as such, with no reference to the strength of any evidence and making sure that the reader is not misled.
    ii. If there are no, or insufficient, data available no evaluative report can be produced, e.g. if there are no or very few data on the occurrence of a particular 'marker' compound in honey assumed to be genuine or known to be adulterated. ER may be based on peer reviewed scientific publications. Note however that ER is acceptable based on unpublished data and professional expert opinion, always provided that the use of such data can be justified. Such data can take the form of, for example, internal databases or reports or, in addition to or in the absence of the above, be part of expert knowledge built upon experiments conducted under controlled conditions (including case-specific experiments), training and experience. See also page 15 of the ENFSI Guideline[39].

e) If ER can continue assign the LR by choosing an appropriate numerator and denominator. Regarding markers the numerator can be informed by the relative frequency at which the marker is found in adulterated honey. It is not appropriate to base ER on a circular argument that assumes without supporting evidence that because a compound is found in a limited number of honey samples a honey sample that contains the compound is adulterated. Supporting evidence could include e.g. evidence that the marker occurs in sugar syrups, with supporting mechanistic evidence, and is absent or sparce (with numerical data) in a sufficient number of relevant honey samples assumed (preferable known) to be genuine honey. The denominator, on the other hand, can be informed by the relative frequency at which the marker is found in genuine honey.

f) State the LR to the nearest appropriate whole integer and refer to Table 2 for the appropriate verbal equivalent remembering that ranges of likelihood ratio in the table are indicative and should be seen as a continuum of expression of strength of support. It is to be understood that a likelihood ratio of 999 is only trivially different in its overall impact from one of 1001.

g) Formulate the report and if mandated include an interpretation, badging it as an evaluative report and include the pair of propositions considered and the verbal indication of the strength of the evidence. Include the generally accepted elements of an analytical report (see for example ISO/IEC 17025 or GLP).

h) Do not include vague expressions and make clear the assumptions made.

i) Badge the value or strength of the evidence appropriately by reference to the verbal scale (Table 2).

j) Prepare a report based on the principles of ER, see paragraphs 77 and 78.

Examples follow illustrating in principle the application of evaluative reporting.

Example 1: AFGP, 2-acetylfuran-3-glucopyranoside

57. Background: AFGP, (2-acetylfuran-3-glucopyranoside) seems first to have been proposed as a marker for rice syrups by Xue *et al.,* 2013[52]. These authors identified, by HPLC−DAD, a compound that appears to be absent in honey but present in rice syrups and confirmed it as 2-acetylfuran-3-glucopyranoside by MS and NMR. They determined (HPLC) the average concentration of AFGP in the rice syrups examined to be 92 ± 60 mg/kg. AFGP was not detected in any of 160 honey samples obtained from 34 beekeepers located in various provinces of China. These honeys were selected according to strict criteria with a quality charter ensuring their authenticity. Using the developed method, 16 out of 186 honey samples on the Chinese market were found to contain between 21.5 mg/kg and 145.6 mg/kg AFGP and were deemed to be adulterated with rice syrup. Du *et al*. 2015[53] reported AFGP was not found in 106 authentic honey samples obtained from 24 beekeepers in various provinces of China. AFGP was found in 16 out of 200 random honey samples from the market. AFGP is also known as SM-R (specific marker for rice) and is generally regarded as a good marker for rice syrup addition. The amount of AFGP varies widely in different rice syrups, with very little in some and larger amounts in others depending on how the syrup was manufactured and what raw material was used. Thus, it is an asymmetrical marker, finding AFGP present in honey is meaningful but its apparent absence is not a guarantee of authenticity.

58. The following can be stated.

I: Information, a retail sample of honey was taken and analysed including for AFGP; the honey was labelled "Blend of honeys from more than one country/Blend of non-EU honeys. Packed in UK".

E: The concentration of AFGP found on analysis was, let us suppose, 100 ± 20 mg/kg);

Hp: The examined item of honey is adulterated.

Hd: The examined item of honey is genuine.

59. In this example, we have two small datasets of apparently genuine honey (n = 160, and n = 106) in which no AFGP was found. There has been no suggestion to our knowledge of a naturally occurring chemical mechanism that might explain the presence of AFGP in honey. Nor is AFGP thought to arise as an artefact of any honey harvesting procedures. Bee feeding with rice syrup may introduce AFGP at low concentrations into the resulting honey and this should be considered as a function of the amount of carryover of bee feed and the likely concentration of AFGP in the syrup. The concentration of AFGP in the honey sample in this example has been chosen to avoid this possibility. Thus there are no grounds for assuming that the samples from the market in which the marker was found (n = 16/200 and n = 16/186) can be assumed to be genuine. More generally, the probability of finding this marker in adulterated honey, $\Pr(E \mid Hp)$, depends on the proportion of adulterated honeys where the addition of rice syrup was the chosen mechanism of adulteration. For the purpose of the example here let us suppose that the available information and knowledge suggests that this probability is high, let us say, 0.95. The probability of finding the evidence given Hd is less definite. It *could* be suggested that if more authentic honey samples were analysed AFGP might be found to be in fact naturally occurring. It is currently unknown but, say if Xue *et al*., or Du *et al*. had analysed one more authentic sample it might have contained AFGP. Thus

1 in 161 or 1 in 107 authentic samples of honey *might* contain AFGP, which are 0.6% or 0.9% respectively. A similar result can be obtained with statistical (i.e., Bayesian) methods for estimating population proportions that can deal with zero observations in datasets[54]. We might then, at a possible relative frequency of occurrence of AFGP of 0.9%, say $\Pr(E \mid Hd) = \sim$ 0.009. Hence $\mathrm{LR} = \frac{0.95}{0.009} = \sim 105.$ Thus the finding of AFGP can be described as providing moderately strong support for the first proposition, the examined item of honey is adulterated rather than the alternative, the examined item of honey is genuine.

60. If more data are available in the literature (a comprehensive literature search has not been carried out for this example) the LR could well be larger. In addition the data from Xue *et al*. and Du *et al*. can be aggregated, 161 + 107 = 268, and if one more authentic sample were to be found to contain AFGP, i.e. 1/269 = 0.37%, the LR would be

$$\mathrm{LR} = \frac{0.95}{0.0037} = \sim 256.$$

Example 2: Mannose

61. Background information: mannose is a stable, water-soluble crystalline compound naturally occurring in plant and yeast polysaccharides (e.g., mannan, hemicellulose, or cellulose) or in glycoproteins, from which it can be released through chemical or enzymatic hydrolysis. Missler *et al*. (2016)[55] using ^{1}H NMR detected mannose in rice syrups (600–900 mg/kg) and adulterated honeys but found it absent in certain Chinese fennel and acacia honeys. Approximately 8% of 5300 honeys analysed by Missler contained mannose, which they took to indicate adulteration. Schievano *et al*. (2020)[56] investigated saccharides in 61 acacia honeys from Europe and China. European acacia

honeys and one Chinese honey from an authenticated source contained no mannose (<180 mg/kg). Mannose levels were higher in other Chinese honeys (600 – 1700 mg/kg). Schievano *et al*. considered mannose is uncommon in pure acacia honey but may be present due to overfeeding honeybee colonies with industrial sugar syrups during nectar flow rather than post-hive adulteration. See paragraph 68 for more detailed background.

62. As before, we can state the following:
I: Information, a retail sample of honey was taken and analysed including for mannose; the honey was labelled "Blend of honeys from more than one country/Blend of non-EU honeys. Packed in UK".
E: Let us suppose the concentration of mannose found on analysis was 700 ± 150 mg/kg);
Hp: The examined item of honey is adulterated.
Hd: The examined item of honey is genuine.

63. Missler *et al*., 2016[55] showed that certain sugar syrups contain mannose, and mannose is found in honey spiked with such syrups. Schievano *et al*., 2020[56] supported Missler *et al*. Thus, the probability of finding this marker in adulterated honey, $\Pr(E \mid Hp)$, depends on the proportion of adulterated honeys where the addition of certain sugar syrups was the chosen mechanism of adulteration. For the purposes of illustration, the probability of finding the evidence given *Hp* could be set at, say, 0.95.

64. The probability of finding the evidence given Hd is less definite. Honeydew honey and the blossom honeys chestnut and linden naturally contain mannose. Thus, the frequency of occurrence of mannose in genuine honey may be low, say 1%, i.e. for the purposes of illustration the probability of finding the evidence given Hd could be 0.01. This results in a LR of 95, i.e. moderate support verging

on moderately strong support for the evidence given the first proposition rather than the alternative.

$$\mathrm{LR} = \frac{0.95}{0.01} = 95$$

65. It has been hypothesised that honeys in which natural conditions or immature/early harvesting followed by mechanical moisture reduction may promote sufficient yeast numbers (viable or not) from which honey enzymes may hydrolyse the polysaccharides to mannose. Schievano *et al*., 2020[56] found that all (25%, 15/61) of the Chinese honeys on the Italian market they tested contained mannose. Chinese honey is often harvested early and moisture reduced which, it has been suggested, may give rise to breakdown of yeast cells releasing mannose. While this may have a valid theoretical basis it has not been demonstrated by experiment.

66. However it could perhaps be argued that 25% of Schievano's[56] samples or 8% of Missler's[55] samples contained mannose for reasons not associated with adulteration. Thus the LR could be stated as between 4 and 12, i.e.

$$\mathrm{LR} = \frac{0.95}{0.25} = \sim 4$$

or

$$\mathrm{LR} = \frac{0.95}{0.08} = \sim 12$$

67. Hence, despite the apparent persuasiveness of Missler *et al*.'s published data[55] if the above arguments are accepted mannose provides only slight or limited support for the proposition that the honey is adulterated. Indeed Schievano *et al*. considered their findings might derive from overfeeding honeybee colonies with industrial syrups during the main nectar flow period, often regarded as malpractice rather than adulteration. This example Illustrates the need for properly examined data from the databases.

68. Background in more detail (this would typically be placed into an appendix to the evaluative report): d-Mannose, (CAS 3458-28-4, $C_6H_{12}O_6$, 180.16 g/mol), (hereafter mannose), is a C-2 epimer of d-glucose. It is a stable white water soluble crystalline solid, and a well-known food supplement. Mannose occurs in plant and yeast cells in the polysaccharides mannan, hemicellulose, or cellulose or in glycoproteins from which it can be liberated by chemical or enzymatic hydrolysis.[57] Mannose was first proposed as a marker for addition of sugar syrup to honey by Missler *et al*., 2016[5555]. These authors determined mannose by ^{1}H NMR as part of "Honey-Profiling™" based on the Bruker FoodScreener and reported the presence of mannose in three rice syrups (600 – 900 mg/kg), its absence in Chinese Fennel, Acacia and Vitex honey samples and its presence in these honeys (at 700 mg/kg) with rice syrup addition. Some syrups such as beetroot syrup were not found to contain mannose. To 2015 over 5300 honeys had been analysed by Honey-Profiling™ with about 8% of measured blossom honeys contained mannose which Missler *et al*. regarded as evidence of adulteration. Schievano *et al*., 2020[56] applied ^{1}H NMR to determine 20 minor saccharides in 61 acacia honeys of different geographical origins on the Italian market, [Italy (n = 24), Hungary (n = 13), Romania (n = 8), Serbia (n = 1) and China (n = 15)]. One further Chinese honey was purchased from the China Animal Husbandry and Industry Corporation (CAHIC[58]). Mannose was not found (<180 mg/kg) in European acacia honeys on the Italian market nor in the CAHIC sample. Chinese honeys on the Italian market contained mannose, mean and SD: 1400 ± 300 mg/kg, range: 600 – 1700 mg/kg. It was asserted that while mannose can be found in honeydew and in some blossom honey (chestnut and linden) it has never been reported in acacia honey. Schievano *et al*.[56] took the view that their own findings might derive from overfeeding honeybee colonies with industrial sugars syrups during the main nectar flow period rather than adulteration of the honeys post hive.

Example 3: Caramel E150c/d

69. Background: Caramel colour may be added to mimic dark forest honey, Zábrodská and Vorlová 2015[59] and references therein, which give a LOQ for the method of 5 mg/kg. Caramel may also arise on heating starch syrups. Hence its presence in a sample of honey may indicate adulteration. The summary would be:

    I: Information, a retail sample of honey was taken and analysed for Caramel E150c/d;

    E: Caramel E150c/d concentration found on analysis > 5 mg/kg;

    Hp :The examined item of honey is adulterated;

    Hd :The examined item of honey is genuine.

70. The probability of finding this marker in adulterated honey, Pr($E \mid Hp$), depends on the proportion of adulterated honeys where the addition of a heated starch syrup was the chosen mechanism of adulteration. For the purpose of the example here let us suppose that the available information and knowledge suggests that this probability is high, let us say, 0.95. The defence argues that the honey is genuine. By way of illustration let us suppose 10% of genuine honey contains caramel. Therefore, following the defence's proposition that the honey is genuine, Pr($E|Hd,I$) is assigned as 10%, and

$$\mathrm{LR} = \frac{0.95}{0.10} \sim 9$$

71. It has been known for a laboratory, on a positive finding for caramel, to assert

    "…it is possible the product has been adulterated with syrup containing E150c/d (caramel colour)."

    If the evidence is not adduced, only alluded to, this may be misleading and may well only amount to limited support for the proposition of adulteration. Interrogation of the laboratory data on the prevalence of caramel in honey would allow a LR to be assigned and a proper evaluative report to be issued containing a statement of the strength of the evidence. For something approaching moderately strong evidence given *Hp* as opposed *Hd* to it must be supposed (or known) that fewer than 1% (1 in 100) presumed genuine honeys naturally contain caramel, for example LR = 0.95/0.01 = 95. For strong evidence in support of *Hp* over *Hd* it must be supposed (or known) that fewer than 0.09% (fewer than 1 in 1000) presumed genuine honeys naturally contain caramel for example LR = 0.95/0.00095 = 1000.

Dealing with markers in general

72. If the nature and prevalence of the alleged markers are not disclosed, it is difficult to calculate a LR for the competing propositions. However, the above examples demonstrate a viable approach. Again assuming $\Pr(E \mid H_p, I) = 0.95$, let us say we find that more than 1000 presumed genuine samples have been analysed and do not contain the marker. Interrogation of the database as described in Part 1 of this FWD will allow us to gauge how the contents of a database affect the strength of the evidence. We might, for example, find that only 1 in 1060* samples in the database known by various other means to be genuine contain the marker hence $\Pr(E \mid H_d, I) =$ 1/1060 = 0.0009 and LR = 0.95/0.0009 = 1055. This is strong support for the first proposition, the examined item of honey is adulterated rather than the alternative, the examined item of honey is genuine. (*Note 1060 has been chosen for mathematical convenience to illustrate the approach, the approximate number will depend on circumstances and the probability for the evidence given *Hp*)

73. The possibility of combining a series of likelihood ratios should also be considered. This may mean that a series of findings each of which indicates low or moderate support of the evidence (with respect to a pair of propositions) can, under certain circumstances, be multiplied to yield overall strong support.

For example, if Caramel E150c/d and AFGP had been found in the same sample the LR could be stated as $9.5 \times 256 \cong 2430$ which indicates strong support for *Hp* as compared to *Hd* (assuming conditional independence). The permissibility of such combination depends on several factors including the independence of the data, and that the definition of the conditioning propositions must be strictly the same. The data are not independent if they measure the same thing by different techniques. Examples of independent data:

- Stable carbon isotope ratios ('delta values') determined by EA/LC-IRMS;
- AFGP (2-acetylfuran-3-glucopyranoside), also referred to as SMR (specific marker for rice), detected and quantified by LC-HRMS;
- DFA (Difructose anhydride)
- Mannose
- Oligosaccharides

Examples when data are not independent

- Mannose (or any marker) separately detected and quantified by LC-HRMS and ^{1}H-NMR, the data are not independent hence only one may be combined with other data.
- Oligosaccharides are detected and quantified by HPAEC-PAD and LC-HRMS only one of these data may be combined with other data.

74. The approach of combining likelihood ratios should be the subject of further investigation.

75. How could Evaluative Reporting be applied in practice? The dataset on which the strength of the evidence is evaluated should be available, preferably published in a peer-reviewed journal. Failing that, an interrogation of a relevant database could be undertaken. It is further proposed that if adulteration is alleged, the LR-based strength of the evidence must be reported. See also 'Reporting' below and references[60, 61, 62, 63, 64]. Barriers to the implementation of evaluative reporting include

– The evidence base is insufficient (although note that databases contain >20,000 data and that even in the absence of detailed data consensus justified professional expert opinion can be used),
– Reluctance to publish the evidence,
– Reluctance to allow the databases to be examined and the outcome LR's published (or otherwise disseminated),
– Lack of human resources,
– Reluctance to set the norm for the application of strength of evidence to analytical opinions,
– Evasion of responsibilities to adhere to the norm recommended herein.

Thresholds

76. When ER was first advocated for the assessment of the strength of evidence in honey authenticity analysis[10] the example of diastase activity was used to illustrate the application of ER. Diastase was chosen because published data are available on its occurrence in honey and a minimum concentration is set in law. The example proved a valuable learning experience not least in distinguishing information from findings and the pitfalls of including findings, such as diastase activity, in propositions. Despite the apparent attractiveness of threshold values their use by the scientific community risks interpreting a high probability for the evidence given the proposition as a high probability of the proposition given the evidence. This does not mean that threshold values are not helpful in principle, and have their place, for example as legal or regulatory criteria. When thus applied however, interpretation defaults to the proper consideration of the performance characteristics of the methods employed to detect and quantify the marker(s), for example detection capability, measurement uncertainty, and so on. (For a more detailed discussion of the use of forensic cut off or threshold values see Biedermann *et al*., 2018[65]). The diastase example also highlights the importance of context and case-specific

information. Ultimately, in view of its legislative status diastase was dropped as an example of ER.

Reporting

77. The purpose of providing an analytical report is to provide the recipient with information on which to make a decision that will guide the appropriate action to take (see also 'decision maker' paragraph 10). To maximise the usefulness of the report any opacity in the findings and, if given, an opinion, must be minimised. Establishment of appropriate dialogue between the laboratory and the report recipient prior to, during and after sending a sample is useful in this regard, see for example[66]. Information that should accompany a submitted sample should also be agreed. Of prime importance is that the analytical report itself must be clear, and contain the information needed. Thus, in addition to metadata such as a unique identifier, names and addresses, receipt and testing dates and so on (see for example UKAS) reports should:
    a) Include sufficient information to enable an informed decision, including identification of the method(s) and appropriate method performance characteristics such as LOQ, recovery, measurement uncertainty, precision, and bias.
    b) Be robust, logical, transparent and balanced.
    If an opinion is given the strength of the findings must be given as recommended in this Framework Document.
    c) Otherwise, the report must be clearly marked as not capable of supporting a definitive judgement about the samples, and is being provided for 'intelligence', 'investigative' or 'technical' purposes so that further work can be undertaken.
    d) See also UKAS, LAB 13 Edition 4 November 2022 UKAS Guidance on the Application of ISO/IEC 17025:2017 Dealing with Expressions of Opinions and Interpretations, and UKAS, LAB 48 Decision Rules and

Statements of Conformity, available to download from the publications section of the UKAS website.

78. An example of the elements of ER that must be included in an evaluative report are:
    a) The Title: **Evaluative Statement** or **Evaluative Report**
    [Note: It is important to label/identify the nature of statements or reports: e.g. is it an evaluative report (rather than a technical report which is without an evaluative section/conclusion)]
    b) **Information**
    [An evaluative report / statement should include task-relevant information, e.g. where exactly does the examined item come from (where and when has it been sampled / seized, by whom, how was it stored, conditioned and delivered etc.), i.e. any information relevant to the question/issues that the evaluative report seeks to help with. For example. "I understand from information supplied by ... that on dd/mm/yy the samples(s)/item(s) xyz were sampled / seized. I also understand that [include any other relevant information].
    c) **Samples/Items received**
    Describe the samples / items factually.
    [Chain of evidence details … seal intact, unopened etc …the usual details]
    d) **Request**
    I have been asked to analyse / examine item(s) xyz. This analysis/examination was done in order to help [Mandating party] assess whether the samples / items [claim 1; e.g. adulterated] or [claim 2; alternative; e.g. genuine]. [This provides clarity about what the purpose of the analysis was.]

e) **Nature of analysis/examination(s)**

Explain methods chosen as a function of the nature of items received (as described above) and the request of the mandating party (also as described above). Explain what/how the analytical target(s) is/are relevant to the issue (the request). Suitable background information should be given, see for example paragraphs 57 – 71. The background information is often given in an appendix, with references, to the report although an initial brief summary may also be given.

f) **Results with appropriate units**

Example 1: A retail sample of honey was taken and analysed for mannose by an accredited method xyz within 5 days of receipt.

On analysis the sample contained nnn ± nn mg/kg mannose.

Example 2: A retail sample of honey was taken and analysed for mannose by an accredited method xyz within 5 days of receipt.

On analysis mannose was not detected (LOQ 180 mg/lg)

g) **Evaluation**

I have used the following propositions to assist in my interpretation of the findings:

– the examined item is adulterated

– the examined item is genuine

[Next, explain how the analyst/examiner assigns the probability of the findings given each proposition and the information]

– [Then state that it is X times more probable to observe the findings if [proposition*] is true rather than [proposition*] is true (*insert the appropriate proposition).]

h) **Opinion/conclusion**

In order to determine the weight to be given to the observations/results obtained, I have adopted the framework recommended by [the IHAD WG Framework document, [and cite the publication].

This recommended approach consists of considering the probability of the results if the hypothesis [prosecution] is true and the probability of these results if the hypothesis [defence] is true. Probabilities were assigned based on published studies [citation required] and my expert knowledge [supporting evidence may be required]. These probabilities make it possible to give an order of magnitude as to the strength of the results obtained in favour of one or the other of the hypotheses.

In this case, I am of the opinion that the results obtained are of the order of [EXAMPLE] 8 times more probable if the examined item [is adulterated], rather than if it is [genuine]. The results therefore weakly / [or moderately strongly / strongly / very strongly, depending on the LR] support the [prosecution's] hypothesis (i.e., adulteration), rather than the proposition put forward by [defence] (i.e. genuine).

i) **Explanatory Note**:

The evaluation of the results as reported here depends on the information that was transmitted to me and the assumptions that were made on this basis. If this information turns out to be incorrect, or if new elements become known, please contact me to discuss if I need to reconsider the evaluation of the results presented in this report. [Note that this is noted conditionally as "discuss if I need to reconsider" because not every change in information impacts the value/interpretation of the results.]

j) **Records**

A record of all measurements made, and all case-notes including the considerations made during the assignment of the value to the findings are contained in the case file held at the laboratory and this is available for inspection (and disclosure) if required.

Official Controls and use of reports

79. Laboratories reporting on food samples should be aware of the official and forensic context in which their reports will be used. On the one hand, there may not be a forensic context either immediately or at all. For example, when testing is focused on screening for anomalies, or as part of an authenticity testing plan and general regime in which results that do not fit the model lead to further testing, sampling, and investigation. The sampling and analysis exercise may be batch matching against additional authentic samples taken from a similar area. In these situations, no interpretation or 'not enough information to interpret' may be a reasonable conclusion, preferably accompanied by what more information is needed.

80. On the other hand, in the UK and in the EU food production is subject to official controls. This can include the power of competent authorities and their delegates to carry out inspections and internal audits as well as to take enforcement action. Official controls are described in the assimilated EU legislation on Official Controls[67] especially at articles 7 to 9 and (in the UK) the Official Feed and Food Controls Regulations 2009, made separately in England, Scotland, Northern Ireland and Wales[68] as amended, see especially regulations 4 and 5 of the English regulations and their devolved equivalents. Guidance is also provided by the FSA Food Law Code of Practice (England) (Northern Ireland) and (Wales) and the FSS Food Law Code of Practice (Scotland)[22]. It is a characteristic of such powers that an authorised inspector

may have access to electronic records and may require a food business operator to afford assistance to obtain access to such records. Refusal by a food business operator without reasonable excuse may constitute an offence of obstruction. The authorised officer may not disclose trade secrets except in the course of his duty (for example, in reporting to the Secretary of State or in enforcement action). A report obtained in the context of preparation for legal proceedings or obtaining legal advice may be protected by legal privilege and investigators would not ordinarily be entitled to see such documentation. The consequence of this structure is that, unless privilege applies, an authorised officer may be entitled to see and consider reports obtained in the context of exercising an official control but would not be permitted to disseminate their content except in a regulatory context.

81. In respect of the composition of any honey under investigation, furthermore, food law is primarily enforceable by criminal law, although administrative measures may initially be adopted, such as improvement notices and prohibition orders (see Food Safety Act 1990[4747], sections 10 and 11). Food samples may be taken by officials charged with food law enforcement (see Food Safety Act 1990, section 29) and treated in accordance with the Food Safety (Sampling and Qualifications) (England) Regulations 2013, made separately in Scotland, Wales and Northern Ireland, all as amended[69]. This brings a forensic context to data analysis, whether the results are to be used by the prosecution or the defence.

82. In cases where this is relevant, the concept of *mens rea* ('criminal intention') to show criminal intent and guilty knowledge, where these are components of the crime, rather than accident or negligence must also be noted.[70] Thus in a prosecution for fraudulently mislabelling honey, for example, the onus is on the prosecution. Matters requiring proof must be established to the criminal

standard, ‘beyond reasonable doubt’.[71] The phrase ‘beyond reasonable doubt’ is now regarded by most Crown Court judges as less clear as a jury direction than ‘satisfied so that you are sure’. However, note that what the jury need to be sure about is the fraud. Evidence drawn from a database may form part of what the jury will consider but a jury could find fraud on other evidence and/or reject any information about the database. The database, as an item of evidence, may be found to be inadequate or a jury might come to a view that there was no dishonesty i.e. human error or incompetence rather than fraud.

83. In passing we might note that it is very likely that a dispute about authenticity would be addressed in the regulatory court of the magistrate’s court where very many sorts of technical battles are tried. If a case were to be dependent on the outcome of an assessment of the trader's database, it would be very likely to take place in front of a professional judge and not before a jury.

84. In official quantitative analysis ‘beyond reasonable doubt’ or ‘satisfied so that you are sure’ can be taken as a mean recovery corrected result minus the expanded measurement uncertainty calculated with a coverage factor of k = 2 which gives a level of confidence of approximately 95%. See for example European Commission guidance on the interpretation of compliance control of aflatoxins in food[72]. The appropriate standard of proof for the defence and for both parties in civil cases, is the balance of probabilities (i.e. more likely than not that the relevant facts have been established). Analytical results may only be adduced in a UK prosecution if a formal three-part sample is taken, (see Food Safety (Sampling and Qualifications) (England) Regulations 2013[69] and FSA Food Law Practice Guidance (England), (Northern Ireland) and (Wales) and FSS Food Law Code of Practice 2019 [22] (Sampling and analysis). It is likely that the prosecution in a criminal trial will be obliged to disclose the data on which honey (or any) authenticity findings are based, for example molecular

markers or NMR profiles, in particular material that is capable of undermining the prosecution case and/or assisting the defence[73]. It is therefore insufficient for the analyst to give only opinion; there must be sufficient information before the court to allow it to arrive at a conclusion and the defendant should have such information as could enable a rebuttal defence to be advanced if scientifically available.[74] The court must be provided with the necessary criteria against which to judge scientific conclusions and if an inference is given from the findings, an explanation is expected on how safe or unsafe it is and the margin of uncertainty.[75]

85. The consequences of food fraud or crime can be severe, and reputational damage from alleged food law contravention may also be severe, for example the anecdotally reported 15% to 30% decrease in Australian honey sales costing the industry upwards of $10 million following adverse media comment based on NMR results[76]. The criminal burden of proof 'beyond reasonable doubt', mandatory for food law enforcement, thus seems appropriate too for certain instances of less formal reporting.

86. Two situations in particular may give interpretive difficulties. (1) For blended honeys it is generally necessary to go back to the packer to get the blending information before forming an opinion on the meaning of the test results. In general, blended honeys may present significant challenges to the interrogation of a database. (2) Inappropriate bee feeding might stand out among a set of data from similar origins but may present interpretational challenges and may prompt the question if this aspect has been investigated in populating the database.

PART 3 Findings, Conclusions and recommendations

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Findings

This document outlines the development of a framework by the IHAD WG to evaluate the fitness-for-purpose of proprietary databases of purportedly genuine honey data used to interpret the results of analytical methods for honey authenticity. The framework describes honey and its analysis for authenticity and adulteration, international Codex Alimentarius standards and EU and UK regulation of honey authenticity. The framework details the optimum approach for examining a database's scope, composition, metadata, representativity, and validation of methods to ensure reliability. Safeguards for database owners are described.

The main findings of the IHAD WG are as follows.

a) Honey authenticity investigation is complex due to the diverse botanical and geographical origins of honey, variations in bee species, and honey harvesting practices.
b) Analytical techniques, especially Nuclear Magnetic Resonance (NMR) spectroscopy, are powerful but face acceptance issues due to proprietary and opaque databases.
c) The key components of the Framework include factors such as database scope, data quality, and metadata that must be scrutinized when assessing database adequacy. Detailed questions for the database owner are listed in three appendices (Annex 2). A review exercise with a database holder confirmed the feasibility of applying the framework and its appended questions and led to additional guidance to the appendices. (Annex 3).
d) Confidential data transfer and safeguards for proprietary information are essential to balance transparency and intellectual property protection. Infoculture Ltd, presented to the WG on the development and implementation of a data trust framework including both technical, legal and organisational

components designed to facilitate collaboration among stakeholders in the honey industry.

e) Inspired by its use in forensic science, the framework describes evaluative reporting (ER), a likelihood ratio (LR) based approach to assess the strength of evidence for honey authenticity. Examples of ER application are given including the evaluation of AFGP, (2-acetylfuran-3-glucopyranoside), mannose, caramel and markers in general to help gauge authenticity. Scrutiny of proprietary databases, some containing tens of thousands of data, may provide sufficiently powerful datasets to enable robust ER to be achieved.

f) It is expected that in an evaluative report the strength of the evidence should be described appropriately and the report itself badged as evaluative. If, for whatever reason, ER is not possible or not intended the report must be badged as a technical, investigative or intelligence report as deemed appropriate in the context of the case.

g) The analytical technique, the database used to interpret the results of analysis and the way in which these are reported should all enable reliable, transparent and robust evidence to support decisions in legal, regulatory or other contexts.

h) Science and best practice develop over time. Databases may develop and change over years or decades. The FWD, investigations based on it or findings thereof are not expected to be a counsel of perfection. Rather, the FWD may be used to gauge the appropriateness of an authenticity claim made in any sector of the food industry or as guidance for potential investigators on the examination of allegations made against the authenticity of a food. The FWD can also be considered as an educational tool raising standards for database owners.

i) Methods of analysis must be properly validated prior to being applied to assess honey, and food authenticity in general. It is recommended that, to demonstrate fitness for purpose and for harmonisation of global acceptance, the methods are accredited to an international standard such as ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories. Specific or generic accreditation as appropriate should be considered. Performance characteristics are especially important. Accreditation of opinions, where available, should also be considered.

Conclusions and Recommendations:

Database Interrogation:

Standardised approaches for database scrutiny and representativity evaluations are necessary, recognising that a balance must be struck between a counsel of perfection and the ability to hold to account reported findings and the weight accorded to the evidence.

The WG proposes a set of detailed questions to guide the interrogation process that we commend to any organisation required to adjudicate on honey or any food authenticity based on analytical data interpreted by means of a database of purported genuine samples.

The WG suggests consideration be given to the establishment by an external provider of a trust framework for confidential data transfer. This exercise could be the subject of a future research proposal.

Evaluative Reporting (ER) Implementation:

ER should, where appropriate, be integrated into honey authenticity evaluation and reporting. It is appropriate to apply ER when a competing pair of propositions as to the authenticity of the sample in question can be set by the specific case circumstances or indicated by a regulator or other mandating authority. This is not intended to replace technical, investigative or intelligence reporting. In an evaluative report the strength of the evidence must be described appropriately and the report itself badged as evaluative.

Future Applications:

The framework can be generalised for other food authenticity databases, enhancing global food fraud detection capabilities.

Collaboration and Transparency:

Collaboration with database owners and regulatory bodies is critical for ensuring that the framework's findings are actionable and reliable.

Adoption of non-disclosure agreements (NDAs), peer-reviewed validation and the development of a process for confidential data transfer can increase trust in the process. The latter could be achieved through a further cross-government project aiming to enhance the transparency and reliability of honey authenticity data through collaboration and technological advancement.

Continuous Improvement:

This framework contributes to continuous improvement in scientific investigation of food authenticity and food fraud by providing tools to interrogate databases of authentic samples and by describing evaluative reporting as a model for quantitative metrics of the weight of evidence to be attributed to results of sampling and analysis. The WG emphasises the need for:

- Ongoing training, on both the framework developed herein for the scrutiny of proprietary databases, and the application of evaluative reporting. These could be achieved through further cross-government (e.g. LGC/DEFRA) KT projects.
- Further research and guidance on evaluative reporting applied to food authenticity.

– Further research, and updates to the framework to adapt to new challenges in food authenticity.
– Knowledge transfer and education of stakeholders, to raise standards in, and harmonise the reporting of, results of analysis so that valid conclusions may be drawn more quickly and robustly by decision makers.

Glossary

AFGP	2-acetylfuran-3-glucopyranoside, see also SMR
~	A symbol meaning 'approximately'
^1H	Proton, as in ^1H NMR which is proton Nuclear Magnetic Resonance spectroscopy
A vertical bar |	To be read as 'given'
Accredited method	A method of analysis accredited to the standard ISO/IEC 17025
AOAC	Association of Official Agricultural Chemists, https://www.aoac.org/about-aoac-international/
C_3 (sugars)	The most common metabolic pathway to capture carbon dioxide in plants from which sugars are formed. Atmospheric CO2 contains two carbon isotopes, ^{12}C and a small amount of ^{13}C. Plants can fractionate the carbon isotopes in different ways providing a means of potentially differentiating C_3 plant sugars from sugars derived from other metabolic pathways.
C_4 (sugars)	A less common metabolic pathway to capture carbon dioxide in plants, although several important crops follow this pathway, e.g. cane sugar and corn (maize), see also C_3
CAHIC	China Animal Husbandry and Industry Corporation
Chemometric	Relating chemical measurements to a property of interest through the application of mathematical or statistical methods.
Codex	Codex Alimentarius
Coverage factor, k	A multiplier chosen to calculate the expanded uncertainty of a measurement.
Decision maker	See paragraph 10
Defra	Department for Environment, Food & Rural Affairs
Delta value	$\delta^{13}C$ values (e.g.“delta thirteen C”), a measure of the Carbon 13 to Carbon 12 ($^{13}C/^{12}C$) ratio
DFA	Difructose anhydride
DNA	Deoxyribonucleic acid
DP	Degree of Polymerisation
E	Evidence
EA-IRMS	Elemental Analysis Isotope Ratio Mass Spectrometry, see also EA-SCIRMS
EA-SCIRMS	Elemental Analysis Stable Carbon Isotope Ratio Mass Spectrometry, see also EA-IRMS
EFSA	European Food Safety Authority
ENFSI	European Network of Forensic Science Institutes

ER	Evaluative Reporting
FSA	Food Standards Agency
FSS	Food Standards Scotland
FTIR	Fourier transform infrared spectroscopy
FWD	Framework Document (of the IHAD WG)
GB	Great Britain
GC	Gas chromatography, see also Government Chemist, the context will disambiguate
GC	Government Chemist, see also Gas chromatography, the context will disambiguate
GC-MS	Gas chromatography coupled to mass spectrometry
GC-MS/MS	Gas chromatography coupled to tandem mass spectrometry
GLP	Good Laboratory Practice
GMO	Genetically Modified Organism
GPS	Global Positioning System
H_d	One of a pair of propositions
HMF	Hydroxymethylfurfural
Honey	See paragraphs 7 and 9 for Codex and EU/UK definitions
H_p	One of a pair of propositions
HPAEC-PAD	High-performance anion-exchange chromatography with pulsed amperometric detection, a technique typically used to separate and determine carbohydrates.
HPLC-DAD	High Performance Liquid Chromatography with diode array detection
HPLC	High Performance Liquid Chromatography
HRMS	High Resolution Mass Spectrometry
I	Information
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
IEC	International Electrotechnical Commission
IHAD WG	Working Group for the development of a framework for interrogation of honey authenticity databases
IR	Infrared spectroscopy
ISO	International Standards Organisation
ISO/IEC 17025	A standard of General requirements for the competence of testing and calibration laboratories
JRC	Joint Research Centre (of the European Commission)
k	Coverage factor, A multiplier of the standard uncertainty to produce desired level of confidence, e.g. all things being well, k = 2) defines an interval having a level of confidence of approximately 95 %.
KT	Knowledge Transfer
LC	Liquid Chromatography

LC-HRMS	LC coupled to high-resolution mass spectrometry
LC–IRMS	Liquid chromatography coupled to isotope ratio mass spectrometry
LC-MS/MS	LC coupled to tandem mass spectrometry
LGC	Laboratory of the Government Chemist
LOD	Limit of Detection
LOQ	Limit of Quantification
LR	Likelihood Ratio
MS	Mass Spectrometry
m/z	Mass to charge ratio, a metric in mass spectrometry
mg/kg	Milligrams per Kilogram (also known as ppm, parts per million, although ppm is deprecated except in NMR
MU	Measurement Uncertainty, see also UoM and *k*
NDA	Non-disclosure Agreement
NIR	Near infrared spectroscopy
NMR	Nuclear Magnetic Resonance (spectroscopy)
OECD	Organisation for Economic Co-operation and Development
PDO	Protected Designation of Origin (food labelling)
Performance characteristics	A set of criteria that determine the effectiveness of a method of chemical or biochemical analysis
PGI	Protected Geographical Indication (food labelling)
Pr	Probability
SCIRMS	Stable Carbon Isotope Ratio Mass Spectrometry
SMR	Specific Marker for Rice (Syrup) see also AFGP
ToR	Terms of Reference
UKAS	United Kingdom Accreditation Service
UoM	Uncertainty of Measurement, see also MU and k
UV-Vis	Ultraviolet and visible wavelength spectroscopy
WG	Working Group for the development of a framework for interrogation of honey authenticity databases

Department
for Environment
Food & Rural Affairs

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