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Extended honey quality assessment with complementary methods enables the assessment of effects of queen excluders in beekeeping management practices

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ABSTRACT

Recent innovations in food quality assessment include measuring food-induced emotions (FIE) and using image-forming methods (IFM), such as copper chloride crystallisation and capillary dynamolysis. FIE analyses the emotional and physical impact of food, while IFM captures the sample matrix to assess its physiological state. These methods have not yet been tested for honey. This study examined whether the use of these methods provides additional insights into honey quality. This study compared honey from organic beekeeping with queen excluder (QE) and without a queen excluder (NQE), sampled from seven beekeepers in Germany over 2 years. No significant differences were found in diastase activity or hydroxymethylfurfural (HMF) content. In 1 year, a slight increase in moisture was observed in honey from hives with a queen excluder. Sensory analysis revealed no differences, but FIE showed significant effects, particularly in emotional characteristics. IFM accurately identified differences between treatments in both 2018 and 2019. Food induced emotions and image-forming methods for assessing food quality generated additional information about honey quality in comparison with standard chemical and sensory analysis. The use of queen excluders can be perceived as a beekeeping management practice that influence honey properties.

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Introduction

Honey is a substance that honey bees (*Apis mellifera*) and some other bee species (e.g. stingless bees of the genera *Melipona* and *Trigona*) produce from plant nectar, plant secretions or honeydew. The bees ‘collect [and] transform [honey] by combining with specific substances of their own, deposit, dehydrate, store and leave [it] in the honeycomb to ripen and mature’ (FAO/WHO 1981). The composition of honey depends on its floral origin, with carbohydrates making up 70–80% and water approximately 15–20% of the

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mass. The carbohydrates are mainly the monosaccharides glucose and fructose (65--80%), as well as many disaccharides and some oligosaccharides. Many other components such as organic acids, proteins, enzymes, hormones, flavonoids, vitamins, essential oils, minerals and many more supplement these in small quantities. The most important enzymes are diastase, invertase and glucose oxidase. The sugar composition particularly influences the properties of viscosity, hygroscopicity and crystallisation behaviour of the respective honey (FAO/WHO 1981).

High moisture levels can reduce the shelf life of honey, as naturally occurring yeasts induce fermentation. Increased water content can be due to harvesting before the honey is ripe or to adverse storing conditions. Hydroxymethylfurfural (HMF) content and proline content allow for conclusions to be drawn on the storage period. HMF is a compound formed during the reduction of sugars, particularly by heating. This thus helps to classify honey as damaged by (re)heating. HMF has 'low acute toxicity in bees but causes increased mortality upon chronic exposure' (Bodin et al. 2022), e.g. in bee feed. In cases of low invertase activity and low HMF content, proline content is analysed in order to further validate the ripeness and freshness of honey. Proline is a characteristic component of honey bee saliva. Although this parameter is not subject to any regulation, it is often used in empirical studies as an additional indicator and should not be lower than 200 mg kg^{-1} (Ohe 2010).

Standard methods for honey analysis consist of spectrophotometry, refractometry, titration, chromatographic analysis and pollen microscopy. In Germany, the most frequently used set of methods for honey quality assessment includes determination of moisture content, invertase activity, HMF content, sugar spectrum, pH value, electrical conductivity, and free acids composition using Fourier transform infrared spectroscopy (FT-IR). The floral origin of the honey is determined by microscopic pollen analysis (based on the melissopalynological method developed by Pfister in 1895), which is still the most widespread technique for the determination of the honey variety (Puścion-Jakubik et al. 2020). Also, a sensory test for organoleptic characteristics is included. The sensory method, which was applied from 1979, was later refined in other European countries, most notably in Italy (Piana et al. 2004; Marcazzan et al. 2018). It is generally employed to describe 'visual, olfactory, olfactory-gustatory and tactile characteristics of honey (including their intensity) and confirm the absence of defects' (Marcazzan et al. 2018). In 1998, the International Honey Commission of Apimondia started to develop a harmonised terminology for odours and aroma of European unifloral honeys and a routine method for seven trained assessors (Piana et al. 2004). Piana et al. (2004) highlighted the importance of the continuous development of different methods of sensory analysis, accounting for different economic aims and benefits and building on the experience of traditional methods.

A relatively new approach used to assess food quality is the measurement of bodily and emotional responses to food. Several questionnaires focusing on the perceptions of food-induced emotions (FIE) have been developed (King and Meiselman 2010; Porcherot et al. 2010; Ng et al. 2023; King et al. 2013; Spinelli et al. 2014). FIE measurements are used to assess quality questions, such as evaluating new ingredients (Moss et al. 2024), the importance of portion size (Salazar Cobo et al. 2022), comparing cereal processing methods (Wohlers et al. 2024) and comparing yoghurt product attributes (Schouteten et al. 2017) and milk product attributes (Geier et al. 2025). U. Geier, A. Büssing, et al.

(2016) and U. Geier, R. Greiner, et al. (2016) developed the Empathic Food Test (EFT) questionnaire. A preparatory framework based on the Kabat-Zinn concept of ‘mindfulness-based stress reduction’ was included (Kabat-Zinn et al. 1985). Panellist preparation in terms of body awareness was introduced. In this way emotions can be better perceived as they are localised in the somatosensory system (Nummenmaa et al. 2014).

The image-forming methods (IFM) of copper chloride crystallisation according to Pfeiffer as described by Kahl (2007), Fritz et al. (2011) and Fritz et al. (2017) and capillary dynamolysis according to Zalecka et al. (2010), as described by Fritz et al. (2011) and Fritz et al. (2017), are well known in the organic food sector, but are relatively unknown for investigating product qualities in a general context. These methods utilise the properties of metal salts in aqueous solution to react with organic substances with specific structures. These structures become visible through a carrier – a glass plate in copper chloride crystallisation and a chromatography paper in the capillary dynamolysis. By creating reference images of plants and foodstuffs (Doesburg et al. 2014) and developing standardised visual criteria (Huber et al. 2010), the images can be evaluated.

Copper chloride crystallisation is probably the best-documented holistic examination method. Numerous scientific publications are available. Following a recommendation by the Senate Working Group of the Federal Research Institutes (Tauscher et al. 2003), copper chloride crystallisation has been validated as part of several publicly funded projects (e.g. BÖL projects 02OE170 and 19OE078; Kahl 2007; Fritz et al. 2017). In several studies, this method has shown its potential to differentiate between products from different production systems (Fritz et al. 2011, 2017, 2021). Copper chloride crystallisation has also shown to be suitable as a sum parameter for ripening and degradation processes (Doesburg et al. 2014).

According to the current legislation for honey quality assessment in Germany (Abschnitt § 1 Anlage 1; HonigV-Honigverordnung (2004)), honey is clearly defined in accordance with the Codex alimentarius (FAO/WHO 1981) and the EU labelling rules for honey (EU Council 2024). The German regulation lists general and specific product quality requirements (§2 Abs. 1 and Appendix 2; HonigV-Honigverordnung (2004)). Most importantly, no substance can be added and no typical substance removed from the product. Taste, smell and colour should be typical for honey. In flower honeys, fructose and glucose content should sum up to more than 60 g 100 g⁻¹. Saccharose content must not exceed 5 g 100 g⁻¹. The water content is restricted to a maximum of 20% (23% for heather honey). Electrical conductivity is limited to different values according to the botanic origin of the honey. Free acids should not exceed 50 milliequivalents of acid kg⁻¹ and HMF content of 40 mg kg⁻¹. A minimum value of eight on the Schade scale applies to diastase activity. Honey must not contain more than 0.1 g 100 g⁻¹ of insoluble impurities.

The regulation of the German Beekeepers Association (Deutscher Imkerbund e.V. DIB) is more restrictive, and the water content is generally limited to 18%. The enzymatic activity of invertase must be higher than 64 Siegenthaler units kg⁻¹ (some low-enzyme types of honey are excluded). HMF is limited to 15 mg kg⁻¹ (Deutscher Imkerbund e.V. 2021).

The standards of the Demeter Association (Demeter e.V. 2022) define the following additional quality criteria: Reheating after harvest must not exceed 35°C, HMF content is limited to 10 mg kg⁻¹ maximum. These guidelines do not only refer to product quality, but they also regulate beekeeping management practises (BMPs), e.g. feeding. In recent

years, the use of queen excluders has become a highly controversial beekeeping management practise. Up until 2024, Demeter did not allow the use of queen excluders as a systematic component of the management regime (Demeter e.V. 2022). Queen excluders are metal or plastic grids, wide enough for workers to pass through but too narrow for the queen. They separate the honey combs from the brood nest of the colony. Several people have been presumed to have developed and applied queen excluding devices: Peter Iwanowitsch Prokopowitsch (1775–1850) (Geiseler 2011; Schade 2012), Abbé Collin (Collin 1875 as cited in Crane (1978)) among others. Until now there is no scientific peer reviewed evidence to suggest that queen excluders disturb the colony development or have any other adverse effects (Garrido and Nanetti 2019). The use of queen excluders is a modern standard in mainstream beekeeping, as well as in organic beekeeping. The aims of this beekeeping management practice include to strictly separate brood from honey frames, harvest honey from scarce floral resources, rear queens in queenright colonies or limit breeding. In Africa, queen excluders have been shown to enable the colonies to forage more nectar and limit breeding at peak honey flow (Abi Gemedi 2023). However, the impact of the use of queen excluders has been intensely discussed in applied beekeeping ever since the beginning of its use. In discussions, monographs and journals, the effects of queen excluders are highly controversial. Critics assume that the use of the device reduces honey quality. They argue that climatic conditions in the supers, i.e. top combs where the honey is stored, are altered by the separation from the brood sphere (Gerstmeier and Miltenberger 2018). Breeding requires temperatures of 35°C. Lower temperatures and the absence of actively nectar manipulating worker bees are supposed to hinder the ripening process of the honey, when bees are forced to store the honey outside of the brood nest (Bretschko 1985; Lampeitl 2009; Rindberger 2020). To the best of our knowledge, no scientific experiments have yet been conducted to investigate this assumption.

This study investigated whether honey quality was affected by the use of queen excluders in colonies of seven biodynamic beekeeping operations. In this project, the honey samples analysed came exclusively from biodynamic beekeeping operations, where the management strategies were in accordance with the standards of the Biodynamic Farmers' Association Demeter (Demeter e.V. 2022). All of the seven beekeepers provided two samples in each year. The objectives of the study were to investigate i) whether all samples met the generally high-quality standards according to the regulations for biodynamic honey according to Demeter guidelines and ii) if additional new methods may help to assess the honey quality of samples from different production processes. Therefore, the hypothesis for the present study was image-forming methods (IFM) and the measurement of food induced emotions (FIE) generate additional information about honey quality complementary to sensory and chemical analysis. We hypothesised that honey originating from hives without queen excluder would show higher quality (e.g. being more mature or less aged) characteristics.

Materials and methods

Honey samples

The honey tested in this study was taken in the test years of 2018 and 2019 from 14 experimental colonies by beekeepers from seven biodynamic beekeeping operations

taking part in a four-year research project ‘DeBien’ (Bundschuh et al. 2024). In both years, two honey samples, one from colonies where a queen excluder was used (QE) and one from colonies where no queen excluder was used (NQE), were provided by each of the seven beekeepers. Individual samples were derived from several colonies (mixed sample) for some beekeepers, while for others they were taken from only one honey bee colony. The time of collection corresponded to the respective farm harvest time of the spring blossom or summer blossom honey. The honey was extracted on the individual beekeeping farms with locally used extraction machines and was then dispatched in jars. The sample management was carried out by Forschungsring e.V. (Darmstadt, Germany).

Chemical analysis

Three quality parameters were determined for the chemical analysis: moisture content, diastase activity and antioxidant capacity. The moisture was determined refractometrically (Bogdanov et al. 2004), the diastase activity according to the commercial Phadebas method (Bogdanov et al. 1999; Sakač and Sak-Bosnar 2012; Phadebas 2018) and the antioxidant capacity by means of the DPPH reaction (Lewoyehu and Amare 2019). A low water content, a high diastase activity and a high antioxidant potential are desirable in honey. The tests were carried out at the University of Applied Science Fulda (Fulda, Germany).

The moisture was determined refractometrically according to method L 40.00–2 (BVL Bundesamt für Verbraucherschutz und Lebensmittelsicherheit 1992) in accordance with §64 LFGB. The temperature was kept constant at 20°C using a thermostat in accordance with the regulations. The rather cloudy honeys were heated in a water bath at 45.5°C after homogenisation in order to avoid distortion of the results. To analyse the diastase activity, a sodium hydroxide solution with a concentration of 0.5 mol l⁻¹ was prepared by dissolving 0.5g of sodium hydroxide in 100 ml of distilled water. From each sample, 0.5g of honey was taken three times and dissolved in beakers with acetate buffer. The solutions were then quantitatively transferred to 50 ml volumetric flasks. 5 ml of the honey solution and 5 ml of acetate buffer were pipetted into each test tube as a blank (BW). The phadebas tablets were added at 15 s intervals to ensure the same reaction time for all test tubes. The reaction was stopped with 1 ml NaOH in the same order. The rest of the procedure was carried out according to the instructions (Phadebas 2018).

Antioxidant capacity (AOC) was determined spectrophotometrically at 517 nm via the DPPH reaction. Ascorbic acid was used as a standard. The antioxidant capacity was not quantified directly but was determined as ascorbic acid equivalents (AAE) using a calibration curve (Molyneux 2004). In this study, AAE was expressed in the unit mg AAE kg⁻¹. This refers to the effect of the secondary ingredients in one kilogramme of honey, which corresponds to the effect of a certain number of milligrams of ascorbic acid. Approximately 0.5 g of each sample was weighed out twice and dissolved in 25 ml methanol.

Sensory analysis

The sensory analysis was carried out in the Food Sensory and Consumer Research Laboratory at Fulda University of Applied Sciences in the Department of

Nutritional, Food and Consumer Sciences, Germany, using a profile test in accordance with DIN 10,967-1:1999 (DIN 1999). The panel included 13 trained individuals in 2018 and 14 trained individuals in 2019. A repeat measurement was carried out in both years for all samples. The following characteristics were analysed: appearance, texture, odour, aroma, taste and mouthfeel. The intensity of the characteristics was measured using a 10 cm subdivided scale (from 0 to 10; from imperceptible to strongly perceptible or from clear, transparent to cloudy for the attribute cloudy (appearance), from liquid to solid for the attribute solid (texture), from imperceptible to coarse-grained for the attribute sugar crystals (texture) and from smooth to coarse-grained for the attribute grainy (mouthfeel)), or a 10 cm non-divided scale with each cm marked for the attribute colour (appearance).

Food-induced emotions (FIE)

The physical and emotional responses to the samples were determined using the Empathic Food Test (EFT) questionnaire (Geier U, Büssing A, et al. 2016). Here, FIE profiling was carried out with 7 to 13 trained panellists in four experiments in 2018 (average 10.25) and 10 to 12 trained panellists in four experiments in 2019 (average 10.67), respectively (Geier U, Greiner R, et al. 2016). On average, 10 observers were given a mindful body scan based on Kabat-Zinn's concept of 'mindfulness-based stress reduction' (Kabat-Zinn et al. 1985) before each experiment. The samples were coded (double-blind) and randomly distributed.

The EFT questionnaire (Geier U, Büssing A, et al. 2016) contains 12 bipolar characteristics (Table 1) which are rated in five levels. The method is based on a sensory consumer test according to ISO 11136 (2014). These 12 items can be grouped, as a factor analysis showed (Geier U, Büssing A, et al. 2016), in more emotionally oriented items (summarised by Scale 1), and those which are focusing on physical and mental effects (represented by Scale 2) (Table 1). For the purpose of clarity, only the results of these two scales are presented in this study.

Table 1. The 12 items of the Empathic Food Test questionnaire (Geier U, Büssing A, et al. 2016.).

Individual attribute (item)	Scale
warm – cold	
bright – dark	1
relaxed – nervous	
comforting – unwell	
satisfied – unsatisfied	
balanced – unbalanced	
light – heavy	2
fresh – exhausted	
energised – not energised	
awake – tired	
concentrated – not concentrated	
long – short lasting	

Image-forming methods (IFM)

The image-forming tests were carried out using the copper chloride crystallisation (Kahl 2007) and capillary dynamolysis (Zalecka et al. 2010) methods in the laboratory of Forschungsring e.V. in Darmstadt, Germany. The study was undertaken double-blinded. Two honey samples were provided by each of the seven beekeepers in each year. The honey samples were dissolved in demineralised water at a ratio of 20%. For each sample, 12 copper chloride crystallisation images and 4 capillary dynamolysis images were produced at different honey concentration levels. The copper chloride concentration in each picture was 150 mg, and honey was added in quantities between 40 and 64 mg. For the capillary dynamolysis, the honey dosage was between 40 and 200 mg. For the evaluation, the sets of copper chloride crystallisation images and capillary dynamolysis images were combined.

The evaluator's task was to arrange the paired samples according to similar features of the images and classify them into separate groups (=step 1). Secondly, the resulting groups were described and characterised based on reference images. Thirdly, the samples were assigned to the two beekeeping management methods (treatments). Lastly, the double-blinding was removed to see if the assignment of the samples was correct or incorrect. These assessment steps were introduced by Fritz et al. (2017) and Fritz et al. (2021).

Statistical analyses

For FIE, the two treatments, with queen excluder (QE) and without queen excluder (no queen excluder = NQE), were compared with regard to their mean differences. For both scales, the analysis was conducted separately. Since each beekeeper provided honey from both beekeeping practices, a t-test for dependent data and paired samples was used. Cohen's d value was reported as a measure for effect size, calculated as $d = \text{Mdiff} / ((\text{SD1} + \text{SD2}) / 2)$, with Mdiff = difference in mean values, SD1 = standard deviation NQE, SD2 = standard deviation QE, following the recommendation of Cumming (2012). Cohen's d-values were interpreted as follows: $0.2 > d > 0.5$: small effect; $0.5 \geq d > 0.8$: medium effect; $d \geq 0.8$: strong effect (Cohen 1988). IBM SPSS Statistics version 26 was used for analysis, and *p*-values < 0.05 were interpreted as statistically significant.

The statistical analysis for IFM tested whether the assignments differed systematically from the guessing probability. A binomial test was used (exact probability, confidence interval according to Brown et al. (2001)).

For the statistical analysis of the chemical data, a one-way ANOVA was performed separately for each year. The measured value was used as the dependent variable, and the variant was included as a fixed factor. For the combined analysis of both years, the year was incorporated as an additional fixed factor in the model (two-way ANOVA).

A paired t-test was performed for the sensory evaluation, and Cohen's d was calculated to quantify the effect size.

All data was analysed using IBM SPSS Statistics (Version 26) predictive analytics software.

Results

Chemical analysis

For two of the three chemical quality parameters, diastase activity and antioxidant capacity, no differences were found between the samples with queen excluder (QE) and without queen excluder (NQE). In 2019, the moisture showed a strong tendency to be lower in NQE honeys ($p = 0.07$; [Table 2](#)). When comparing the samples from individual beekeepers (i.e. comparing samples from NQE hives with samples from QE hives from the same apiary), we found that in 2018, samples from four out of seven apiaries showed lower moisture levels in hives without excluder (NQE), in one apiary the groups showed equal moisture levels and in two apiaries, NQE samples contained higher moisture levels. The original data is shown in [Table 2](#).

Sensory analysis

In the sensory profile test, the intensities of visual attributes (4 characteristics), odour (16 characteristics) and taste (18 characteristics) were recorded in a paired comparison between QE and NQE samples for each of the seven apiaries. Only a few significant effects were observed in the sensory analysis. No patterns indicating an influence of the treatment or the year were identified ([Tables 3 and 4](#)).

Food induced emotions

For the evaluation of FIE, both scales in the questionnaire were assessed. In both scales, the average values for NQE were lower than for QE ([Figure 1](#); [Table 5](#)). In EFT, low values have a positive connotation. For Scale 1, the difference between the means ($M_{diff} = 0.35$, $SE = 0.15$) was statistically significant ($p = 0.037$). For Scale 2, the differences ($M_{diff} = 0.28$, $SE = 0.16$) were somewhat weaker and were not statistically significant ($p = 0.105$). The effect size of both differences was large according to Cohen's d (Scale 1: 0.986; Scale 2: 0.811).

There were no significant differences between NQE and QE for the items warm-cold and long-short, which are not part of the two scales ([Table 2](#)).

Image-forming methods

The images from both copper chloride crystallisation and capillary dynamolysis were assigned to two groups in the first assessment step. In the second step, these two groups could be well characterised according to reference image characteristics ([Table 6](#)).

With capillary dynamolysis, the differences between both groups were similar in both harvest years and showed the same order of effect size. With copper chloride crystallisation, the differences were greater in 2018 than in 2019.

In the third step, the two groups were matched with the two treatments (QE and NQE). Based on the experience with the investigation of other management practices (Doesburg et al. 2014; Fritz et al. 2022), the samples of Group 1 were assigned to be less age-related degenerated and more typical for honey compared to Group 2. This

Table 2. Results of the chemical analysis in 2018 and 2019 (QE: with queen excluder; NQE: without queen excluder).

Beekeeper ID	Variant (origin of sample)	Year	Moisture (% water)	Diastase activity (index)	Antioxidant capacity (mg AAE kg ⁻¹)
2	QE	2018	16.07	20.54	42.91
7	QE	2018	16.73	26.04	62.3
1	QE	2018	16.53	32.52	92.04
3	QE	2018	15.73	13.84	1.45
6	QE	2018	17.07	27.66	61.23
5	QE	2018	17.13	24.34	18.31
4	QE	2018	17.40	35.01	27.09
2	QE	2019	16.20	23.90	64.67
7	QE	2019	16.50	22.50	328.33
1	QE	2019	16.80	36.20	96.33
3	QE	2019	16.60	45.00	63.17
6	QE	2019	15.50	25.00	152.50
5	QE	2019	14.90	50.60	511.17
4	QE	2019	18.10	30.30	116.50
2	NQE	2018	16.53	18.32	36.58
7	NQE	2018	17.73	28.49	54.94
1	NQE	2018	16.07	28.18	97.97
3	NQE	2018	15.60	16.42	7.62
6	NQE	2018	16.53	20.74	59.84
5	NQE	2018	17.07	28.26	52.01
4	NQE	2018	17.40	34.12	32.68
2	NQE	2019	16.20	28.70	64.67
7	NQE	2019	15.90	21.50	326.00
1	NQE	2019	16.70	31.50	121.33
3	NQE	2019	16.20	44.20	49.17
6	NQE	2019	15.20	33.60	188.67
5	NQE	2019	14.70	30.70	285.60
4	NQE	2019	16.50	24.70	152.17
Mean value	QE	2018	16.67	25.71	43.6
SD	QE	2018	0.56	6.61	30.8
Mean value	NQE	2018	16.70	24.93	48.8
SD	NQE	2018	0.69	6.01	28.0
<i>p</i>		2018	0.86	0.63	0.747
Mean value	QE	2019	16.37	33.36	190
SD deviation	QE	2019	0.94	10.19	168
Mean value	NQE	2019	15.91	30.70	170
SD	NQE	2019	0.67	6.72	105
<i>p</i>		2019	0.07	0.47	0.787
Mean value	QE	Total	16.52	29.53	117
SD	QE	Total	0.79	9.41	139
Mean value	NQE	Total	16.31	27.82	109
SD	NQE	Total	0.79	6.99	97
<i>p</i>		Total	0.20	0.36	0.841



Table 3. Differences between the sensory profiles (colour and odour attributes) between the honeys from NQE and QE treatments in the paired comparison per beekeeper based on the effect size (Cohen's d).

Beekeeper ID	1		2		3		4		5		6		7	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Attribute														
Colour														
Cloudy	-0.44	-1.17	-0.02	0.77	-0.30	0.43	-0.43	-0.58	-0.48	2.85	0.31	0.08	0.17	0.29
Solid	-0.89	-0.92	0.32	0.13	-0.39	-0.31	0.63	0.29	0.55	0.00	0.48	-0.03	0.64	-0.36
Sugar crystals	-0.67	-0.33	-0.24	-0.45	-0.11	-0.17	0.49	0.87	-0.56	0.11	-0.01	0.16	-0.37	0.31
Odour														
Malty	-0.05	-0.08	-0.29	-0.13	-0.26	0.19	-0.25	0.12	-0.05	0.03	-0.17	-0.07	0.67	0.25
Chestnut	-0.01	0.13	-0.03	0.08	-0.09	0.14	-0.02	-0.14	-0.26	0.60	0.12	-0.14	-0.05	0.14
Resin/pines	0.23	-0.01	-0.51	-0.13	-0.04	-0.13	-0.23	0.00	-0.24	0.20	0.18	-0.03	0.28	0.05
Thyme	-0.14	-0.11	-0.15	-0.24	0.03	-0.33	0.06	0.27	0.11	0.18	-0.02	0.09	0.21	0.01
Hay	0.02	0.05	0.01	0.01	-0.01	0.03	0.21	0.17	-0.13	0.16	-0.27	0.14	0.02	0.13
Chamomile	0.38	0.15	-0.18	0.03	0.34	-0.09	0.12	0.09	0.49	-0.19	-0.16	0.19	-0.13	-0.03
Anise	-0.39	-0.13	0.02	-0.04	0.21	-0.11	-0.13	0.09	0.28	-0.03	0.02	-0.09	0.02	-0.08
Flowers/lime tree	0.16	0.22	0.05	-0.25	-0.46	-0.10	-0.11	0.36	0.19	-0.41	0.15	0.12	-0.14	0.07
Flowers/rose	0.22	0.02	-0.25	0.00	-0.01	0.07	0.11	0.10	0.11	-0.04	0.01	0.14	0.04	-0.13
Honeydew	0.04	-0.01	0.26	-0.27	-0.28	0.32	-0.09	-0.06	-0.01	-0.30	-0.14	0.00	-0.14	0.24
Orange	0.29	-0.11	-0.22	0.19	-0.44	-0.09	-0.03	0.06	-0.18	-0.02	-0.25	-0.11	-0.06	-0.06
Apple	-0.05	0.01	-0.25	-0.02	-0.11	0.04	0.07	0.43	0.14	-0.40	-0.35	0.28	-0.42	-0.04
Dried fig	-0.26	-0.08	-0.23	0.23	-0.22	-0.07	0.20	-0.05	0.20	0.21	-0.11	-0.12	0.04	-0.20
Musty/cheesy	-0.42	-0.20	-0.26	0.12	0.23	0.03	0.22	0.03	-0.16	0.27	-0.40	0.00	0.03	-0.14
Caramel aroma	-0.13	-0.14	0.29	-0.13	-0.33	0.06	0.21	-0.11	0.32	0.13	-0.45	0.11	0.10	0.06
Beeswax aroma	0.05	0.31	0.46	-0.19	0.41	-0.07	0.17	0.13	0.12	-0.26	-0.31	0.15	-0.26	-0.22

Notes: Cohen's d-values with negative sign = higher intensity in the sample from the beekeeping without queen excluder. Cohen's d-values with positive sign = higher intensity in the sample from the beekeeping with queen excluder. d-values were interpreted as follows: 0.2 > d > 0.5, small effect; 0.5 ≥ d > 0.8, medium effect; d ≥ 0.8, strong effect (Cohen 1988). Significant effects are marked in bold.

Table 4. Differences between the sensory profiles (taste attributes) between the honeys from NQE and QE treatments in the paired comparison per beekeeper based on the effect size (Cohen's d).

Beekeeper ID	1		2		3		4		5		6		7	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Attribute														
Taste														
Sweet	0.17	-0.25	-0.05	0.06	0.21	-0.13	0.00	0.13	0.10	0.01	0.23	-0.15	-0.47	0.14
Malty	-0.10	-0.34	0.03	0.31	0.27	0.13	-0.16	-0.05	-0.32	0.21	-0.27	-0.08	-0.04	-0.01
Chestnut	0.11	0.05	0.21	-0.06	0.15	0.13	0.06	-0.17	-0.49	0.25	0.28	-0.06	0.01	0.11
Resinous/harsh	0.24	0.17	-0.34	0.12	-0.31	0.12	-0.21	-0.09	-0.18	0.05	-0.41	-0.19	0.11	0.15
Vanilla	0.15	0.21	-0.13	0.00	0.28	0.02	0.34	0.27	0.01	-0.22	0.12	0.01	0.14	0.02
Lime blossom	-0.35	-0.01	0.00	-0.25	-0.24	-0.07	0.22	0.25	0.13	-0.17	-0.01	-0.05	0.22	0.07
Rose	0.24	0.18	-0.10	-0.21	0.06	0.04	-0.06	-0.14	-0.12	-0.14	0.25	0.19	0.34	-0.02
Honeydew	0.20	-0.15	0.02	-0.33	-0.02	0.16	0.09	0.04	0.28	-0.26	-0.25	0.09	0.08	0.10
Orange	-0.18	-0.14	0.19	0.17	0.35	-0.03	0.01	0.21	-0.31	0.17	0.30	-0.01	0.02	-0.01
Apple	0.22	-0.14	0.17	0.03	0.01	0.03	-0.28	0.16	0.14	-0.28	0.11	0.24	-0.20	-0.07
Sour	0.31	0.06	-0.23	0.25	-0.12	0.19	-0.10	0.17	-0.06	-0.09	-0.15	-0.07	-0.15	0.08
Bitter	-0.20	-0.13	0.04	0.20	0.04	-0.04	0.17	0.00	-0.28	-0.04	-0.30	0.21	-0.16	0.10
Grainy	-0.81	-0.49	-0.27	-0.34	-0.11	0.03	0.25	1.36	-0.43	0.55	-0.11	0.38	-0.10	0.85
Astringent	-0.08	-0.05	0.08	0.12	0.16	0.04	-0.43	-0.05	-0.27	0.02	-0.63	0.03	-0.20	0.36
Sticky	-0.24	-0.27	0.09	0.35	-0.27	0.05	0.16	-0.21	0.37	-0.32	-0.15	0.12	-0.06	-0.28
Melting	0.60	0.25	0.38	0.00	-0.18	0.10	0.21	-0.32	-0.21	-0.13	0.18	0.19	-0.31	0.14
Creamy	-0.30	0.10	0.01	0.04	0.16	0.05	-0.13	-0.47	0.09	-0.25	-0.32	-0.01	-0.21	-0.41
Refreshing	0.16	-0.08	0.47	-0.19	0.24	-0.08	0.16	0.09	0.03	-0.04	0.13	0.24	-0.19	0.04

Notes: Cohen's d-values with negative sign = higher intensity in the sample from the beekeeping without queen excluder. Cohen's d-values with positive sign = higher intensity in the sample from the beekeeping with queen excluder. d-values were interpreted as follows: 0.2 > d > 0.5, small effect; 0.5 ≥ d > 0.8, medium effect; d ≥ 0.8, strong effect (Cohen 1988). Significant effects are marked in bold.

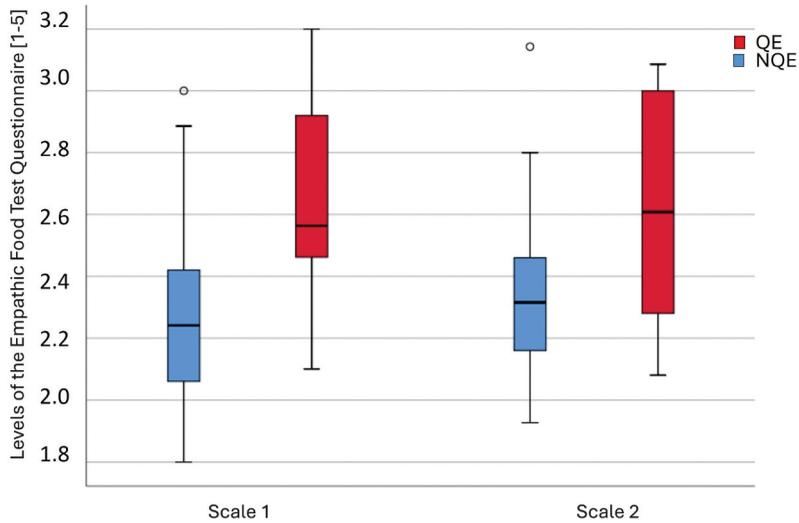


Figure 1. Results of Scales 1 and 2 of the Empathic Food Test (Geier U, Büssing A, et al. 2016) for honey from treatments without queen excluder (NQE) and with queen excluder (QE). The boxplots indicate median values and standard deviation. Possible values range from 1 to 5. Low values are positively connoted, high values negatively connoted.

Table 5. Descriptive statistics. Scales 1 and 2 of the Empathic Food Test (Geier, Büssing et al. 2016) for honey from the samples without queen excluder (NQE) and with queen excluder (QE) shown as the mean value and standard deviation (sd) (all $n = 14$).

		Mean	SD
Scale 1	NQE	2.30	0.37
	QE	2.65	0.34
Scale 2	NQE	2.36	0.32
	QE	2.64	0.36

Table 6. Characterisation of honey samples with the image-forming methods copper chloride crystallisation and capillary dynamolysis.

Method	Group 1 – assigned to samples from colonies without queen excluder (NQE)	Group 2 – assigned to samples from colonies with queen excluder (QE)
Capillary dynamolysis	well differentiated	less differentiated
	regular and impression of movement	impression of less movement
	bright and colourful	less coloured, slightly pale
	little degradation features	clear degradation features
Copper chloride crystallisation	higher plate coverage	lower plate coverage
	well radiated needle tracks	lower needle pass through
	clear centre coordination	centre coordination weaker
	hardly any degradation features	more degradation features

assessment was based on pre-tests with conventional, organic and biodynamic honey (Geier and Bornhütter 2017). According to the experimental hypothesis, the sample of Group 1 was assigned to the NQE treatment and the samples of Group 2 to the QE treatment (Table 6).

For 2018, all 7 pairs were assigned correctly, so the probability of a correct assignment was 1 (95% CI 0.708 - 1). The difference from the guessing probability was significant ($p = 0.016$). For 2019, six of the seven pairs were assigned correctly (Table 7). Over both years combined, 13 out of 14 samples were correctly identified (93%). A binomial test against the random assumption of 50% showed a significant deviation ($p = 0.002$, 95% CI 68–98%), meaning that the person correctly assigned the samples significantly more often than what would be expected by chance. A Fisher's exact test showed no significant difference between the years ($p = 1.0$).

The NQE honey was characterised as more typical of honey (Geier and Bornhütter 2017) and less degraded (Doesburg et al. 2014) than the QE honey. In summary, with IFM, differences were found between QE and NQE honey.

Discussion

In this study, it was confirmed that i) all honey samples from colonies with and without queen excluders met the high-quality standards of the Demeter regulation. The results showed that ii) IFM and the measurement of FIE generated additional information about honey quality complementary to the sensory and chemical analysis and indicated that the use of queen excluders affected honey quality.

Beekeeping practices influence honey quality

This was the first study that tested the effects of queen excluders as a beekeeping management practice in organic/biodynamic beekeeping with regard to honey quality. To date, beekeeping management practices have more often been studied in relation to colony health, performance and survival than in relation to product quality, e.g. Kutby

Table 7. Assignment of the coded samples to the treatments with queen excluders (QE) and without queen excluders (NQE) using the image-forming methods copper chloride crystallisation and capillary dynamolysis.

Beekeeper ID	Year	
	2018	2019
	Correct assignment	
1	Yes	Yes
2	Yes	Yes
3	Yes	Yes
4	Yes	Yes
5	Yes	Yes
6	Yes	No
7	Yes	Yes

et al. (2024) and Steinhauer et al. (2021). A review of the relationships between beekeeping management practices and colony health is available (Sperandio et al. 2019). However, some researchers have provided evidence that specific beekeeping management practices have the potential to influence honey quality parameters: the insoluble solids content differed between traditional African and modern hive types in the study of Kebede and Adgaba (2011). In Lopes et al. (2018), honey from traditional and modern hive types could be separated in a PCA with pollen count, insoluble matter and moisture among others being the main drivers for the clustering of the two production types. In the study by Lopes et al. (2018), the number of samples was even lower compared to that in our study, but the general finding that hive type can influence honey quality was confirmed by Tucak et al. (2004). More and broader studies on the influence of certain beekeeping management practices or beekeeping devices on honey quality would be desirable.

When comparing the research methods, the most pronounced effects between the honey from the NQE and QE management were found in the image-forming methods and in the food-induced emotions. This raised questions as to how these differences can be explained, which has been discussed as follows for each method.

Chemical analysis revealed a tendency towards higher moisture levels in QE honey in one of the two years

Of the three analysed chemical parameters (diastase, HMF value, water content) only moisture showed a tendency towards a difference in 2019, with mean moisture being slightly higher in honey from apiaries with queen excluders. The assumption of lower moisture in the honey when managed without a barrier was supported by the observations of some of the participating beekeepers, according to which the barrier grid delayed the occupation of honey supers and thus the drying of the honey. Ellis et al. (2010) showed that cocoons in brood combs absorbed water from the atmosphere and discussed if this may buffer humidity in the cells which in turn may increase brood survival rates. As the highest brood survival is known to be at between 90 and 95% relative humidity (Doull 1976), a high quantity of water must be stored in the brood comb. Honey with 82.5% solids is in equilibrium with water vapour in an atmosphere at 54.4% relative humidity (Doull and Mew 1977). This suggests that honey that is stored closer to brood cells or in the cocoon filled brood combs with higher humidity (in the brood box or in supers of hives without queen excluder) might lose water less effectively compared to honey in a newly drawn comb (which is always present above a queen excluder). Other beekeeping management practices like supplemental sugar feeding with 1:1 sugar solution may also increase the amount of water in the hive and may possibly also influence the moisture of the honey, but to our knowledge this has not been confirmed so far (Moumeh et al. 2020).

The queen excluder did not appear to affect the sensory properties of the honey

In the sensory profile test, significant differences were only found in some taste characteristics and only with certain beekeepers, no treatment effect was observed and most attributes were not distinguishable between treatments. Specifically for honey, few

studies have linked the sensory profile with other quality characteristics, i.e. mostly the genuine floral origin, e.g. Kumar et al. (2018) and even fewer with beekeeping management practices. Exceptions are Moumeh et al. (2020), who did not detect differences in the flavour and basic taste of honey from colonies fed with different commercial sugars and without supplemental feeding, but they found significant differences for colour and chemical odour attributes. It seems reasonable to assume that the forage and feeding influences the hive product. Other beekeeping management practices related to the choice of the hive systems, devices or materials do not directly influence honey bee nutrition and therefore seem less obviously connected to honey sensory properties, which might be an explanation why little differences between QE and NQE treatments were found. However, indirect effects are still possible: in the study of Taha and El-Sanat (2007), comb age (which can depend on the hive system and the ease of removing combs) was found to influence colour, taste, viscosity and sourness of honey. The honey produced in combs aged one-year had the best qualities compared to older combs.

Image-forming methods

Of the two image-forming methods (IFM) used, copper chloride crystallisation has been the subject of particularly intensive research. In several studies, by using IFM, samples from different cultivation systems could be distinguished and correctly assigned (Fritz et al. 2017, 2019; Athmann et al. 2022). Kahl et al. (2014) and Kahl et al. (2017) were able to show that copper chloride crystallisation was able to detect the influence of food treatment/processing, in the case of milk the influences of homogenisation and heating and in the case of apple juice the influence of filtration. Weibel et al. (2000) compared the quality of organically and conventionally produced apples using several methods, including sensory profiling and the analysis of health-related ingredients. In the study by Fritz et al. (2022) on wine from conventional, organic and biodynamic production, sample differentiation using IFM was also greater than with sensory profiling. Thus, recent scientific studies have shown that some effects can be better shown by IFM than by chemical or sensory analysis, which is in line with the results of this study. These additional pieces of information can inform the evaluation of food quality. Stating this, we have to keep in mind that all the samples in this study met the honey quality criteria of the Demeter association, which are based on chemical parameters.

Food-induced emotions

With FIE differences between NQE and QE were shown. So far, no studies on honey quality using FIE have been published. In recent years, FIE has been applied to evaluate effect of methods of grain processing (Wohlers et al. 2024) and milk processing (Geier et al. 2025). In this study reported here, FIE enabled greater differences between treatments to be identified than the sensory analysis. This confirmed the findings of Geier et al. (2025) on milk quality and underlined the potential of the FIE method for food quality assessments.

Challenges and subsequent research questions

This study had limitations. The 14 samples were taken from seven farms in 2 years. A spatially and temporally more comprehensive dataset would be desirable to strengthen the reliability of the results. The applied methods can only be compared to a limited extent because the statistical analyses were carried out differently.

Further research is needed to clarify which factors led to IFM and FEM achieving different or clearer differences than chemical analyses or sensory profiling. Current research pointed to the importance of the surrounding matrix of substances for the health value of food (Thorning et al. 2017). This may offer one approach of an explanation. In a study of breakfast cereals processed in different ways, the comparison of health-relevant ingredients with the emotional profiling showed broad agreement in the main results (Wohlers et al. 2024). U. Geier, R. Greiner, et al. (2016) showed in a comparison with consumers that similar product pairs (of sugar and milk) were rated differently in a sensory test and a test for FIE. One approach to understanding this is the different temporal dynamics (Jager et al. 2014) in the observation of sensory and emotional characteristics.

In the study by Geier et al. (2025), differently processed milk qualities were compared using several methods; while fat analysis provided information about the cows' feed, sensory profiling and FIE by trained panels separated the samples more in terms of processing intensity.

To beekeepers who want to consider the results of this study in their management decisions about whether to use queen excluders or not, it can be pointed out, that, there is no right or wrong answer. Given the results of the larger study design presented in this article and elsewhere, the device did not affect colony development (Bundschuh et al. 2024), did not save labour despite having brood in honey supers (unpublished data) and slightly affected honey quality (as shown here). So, the decision still depends on individual beekeeper priorities and what suits their operation.

Conclusions

The results of this study supported the hypothesis that testing for food-induced emotions (FIE) and with image-forming methods (IFM), compared with chemical analysis and sensory analysis, provided additional information about honey quality. Based on the results of IFM and FIE, the use of queen excluders can be seen as a beekeeping management practice that influences honey quality.

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Disclosure statement

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Data availability statement

The original data are available from Forschungsring e.V. (Uwe Geier, Tabea Meischner) upon reasonable request.

Author contributions

Jana Bundschuh was drafting the introduction and the discussion and took a leading role in editing the manuscript. Gesine Mandt, Julian Keller and Roya Bornhütter conducted the data collection. Tabea Meischner was reviewing and formatting the manuscript. Christopher Brock was the project coordinator. Uwe Geier was coordinating the data collection and drafting the material and methods and the results sections.

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