New Zealand, a country that has many serious weeds.[9]

Of course bees do provide enormous benefits to mankind, and it is always going to be difficult to persuade beekeepers that their bees could be doing harm. However, we should not regard bees as universally benign. The precautionary principle argues that we should prevent further deliberate release of exotic bee species (such as of bumble bees in mainland Australia). Unlike many of the other impacts that man has on the environment, introduction of exotic species is usually irreversible. It would also be sensible to avoid placing honey bee hives within environmentally sensitive areas, particularly areas where the native flora is threatened by invasion with honey bee-pollinated weed species.

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DAVE GOULSON

Ecology and Evolution Group, School of Biological Sciences, University of Southampton, Bassett Crescent East, Southampton, SO16 7PX, UK

dg3@soton.ac.uk

Original article

Beeswax: quality issues today

STEFAN BOGDANOV

This article concentrates on the main quality issues of *Apis mellifera* beeswax: production by bees and processing by beekeepers and manufacturers, overall chemical composition, as well as sensory and physicochemical characteristics. The main quality issues today are adulteration and contamination. Contamination from the environment being relatively small, the main contaminants are synthetic and persistent acaricides used in beekeeping. Measures for prevention of contamination are discussed. Information on beeswax economy, as well as on beeswax uses is given.

The Greek philosopher Aristotle believed that beeswax originated in flowers, and this theory predominated until the Renaissance. In 1744 the German scientist Hornbostel[26] reported that bees themselves produce the wax. This report was ignored by the scientific community until Hunter in 1792[28] and Huber in 1814[27] published their work. In 1903 the process of wax synthesis was described in detail by Dreyling.[20]

In this mini-review the main quality issues on beeswax will be discussed, without going into details, which can be found in the cited references.

Wax production in beekeeping

Bees need wax as construction material for their combs. They produce it in their wax glands, which are fully developed in 12- to 18-day-old workers. In older bees the wax glands diminish their activity, however, in emergency situations wax synthesis can be reactivated. The greatest quantities of wax are produced during the growth phase of honey bee colonies, under moderate climate conditions during April to June in temperate climates.

The main raw materials for wax formation are carbohydrates, i.e. the honey sugars fructose, glucose and sucrose.[51] The ratio of sugar to wax can vary from three to 30 : 1, a ratio of around 20 : 1 being typical for central Europe.[51] The stronger the colony, the smaller the ratio, and the more economical the wax production for the colony. One Langstroth frame, containing only 100 g of wax can hold between two and four kg of honey.

THE PERFUME OF BEESWAX

Give me some wax that bees have made
And I will offer you in trade
A candle that is aromatic
Pure, unique and charismatic
by Grant D Morse

Wax production and comb construction activity in the honey bee colony are determined by following factors:

- **Nectar flow:** the greater the flow, the more combs are needed for storage.
- **Brood rearing (egg laying):** the more eggs are laid, the more comb cells are needed.
- **The presence of a queen:** only colonies with a queen build combs.
- **Temperature:** temperatures higher than 15 °C favour comb building activity.
- The presence of pollen as a protein source.

The wax economy of bees seems to function according to the supply and demand principle; there is no unnecessary wax production!

Apis mellifera produce wax in their specialized wax glands, found on the ventral side of the abdomen. A bee has four pairs of glands. The liquid wax is delivered by these glands and cools down immediately to form fine, white wax scales. These scales are taken by the hind legs and processed with the mouthparts. A wax scale weighs about 1 mg, so that about one million scales are needed to produce one kg of wax. More details on the biology of beeswax are given elsewhere.[24] The colour of the freshly produced beeswax is white, later it turns to yellow. This yellow colour originates from propolis and pollen colorants. Beeswax has a characteristic odour, originating from the bees, honey, propolis and pollen.

Each year beekeepers should discard the old combs, thus stimulating the bees to build new combs. On the one hand this is a hygienic measure, on the other hand it serves the beekeeper to increase wax production. The dark colour of old combs is caused by larval faeces, pupal skins and from propolis. Old combs must be exchanged regularly at an interval of about two to three years, to be melted down for the production of pure wax. Small-scale wax melters for home wax production are available, but most beekeepers give their combs to wax manufacturers, who also produce foundation comb. The yield of pure wax depends on the method of wax production and on the proportion of old honeycombs used. Usually yields from 30 to 50% are obtained, but they can be nearly 100% if freshly built honeycombs are used.

The practical details for production of beeswax from combs is described extensively elsewhere.[17] The quality of pure beeswax obtained depends greatly on the production methods used. There are two wax extraction methods: melting – the most frequently used method – and chemical extraction. Wax can be melted by boiling water, steam or by electrical or solar power. Chemical extraction by solvents is feasible only in a laboratory, where only small-scale wax production is needed.

After melting and cleaning, beeswax normally has a beautiful yellow colour. If it is dark for any reason (e.g. from overheating or the presence of metals) it can be brightened simply by exposing it to the sun[17] or by chemical means (see 'Factors in producing high-quality beeswax'). The use of complexing agents which bind the metals has also been proposed[17] but these chemicals are problematic from a toxicological and ecological point of view.

Wax blocks are dried and stored in a dark and cool place. For best preservation of colour and aroma, they can be stored in wrapping-paper, placed on shelves or in containers made of stainless steel, glass or plastic.

Details on beeswax manufacturing can be found elsewhere.[10, 17, 43, 50]

FACTORS IN PRODUCING HIGH-QUALITY BEESWAX

- Heating at too high temperatures and for too long may damage the wax and darken its colour.
- Wax should not be heated in containers made of steel, aluminium, zinc or copper because these metals can discolour the wax turning it dark. Do not use lead containers because of contamination. Stainless steel is most suitable.
- Purify beeswax by melting it in a water-bath with water at 70-80 °C for at least 8 hours. Use only the pure upper layer of wax.
- Combs containing fermented honey should not be used as this gives the wax an 'off' odour.
- Heat-resistant spores of American foulbrood (*Paenibacillus larvae larvae*) are not killed by boiling wax in water. Only heating under pressure (1400 hPa) at 120 °C for 30 minutes kills all spores.[38]
- Water-wax emulsions can occur if hard water is used. Soft water with a low mineral content should be used if such problems arise. However, in some cases, water-wax emulsions can occur even with soft water. It is most important that raw molten wax in contact with water is kept below 90 °C.
- Use 2–3 g of oxalic acid per kg wax and 1 litre of water to bind calcium, prevent emulsion and to brighten wax at the same time.[46]
- Wax brightens also by adding acids: 2 g citric acid or oxalic acid, or 1 ml concentrated sulfuric acid per kg wax and 1 litre of water.
- Wax can be bleached white by adding hydrogen peroxide. It is essential that all the peroxide is used up in the bleaching process. Excess peroxide can cause problems in the manufacture of creams and ointments.
- After melting, the wax is not yet pure enough. For additional cleaning, heated water tanks made from high-grade steel are suitable. The wax should remain for some time (best left over night) in the water-bath at a temperature of 75–80 °C. Since wax is lighter than water, it floats. The dirt that sinks to the lower layer of the wax must be scraped off after cooling. Under industrial conditions liquid wax is cleaned by filtration. Wax can also be purified by hot filtration.
- Let the wax cool down as slowly as possible and avoid all movement of the container during cooling.
- The use of solvents to purify beeswax will result in a loss of some of the aroma components.

TABLE 1. Major and minor components of *Apis mellifera* beewax.[47]

Component	Quantity g/100g	Number of components major	Number of components minor
Monoesters	35	10	10
Diesters	14	6	24
Triesters	3	5	20
OH-monoesters	4	6	20
OH-polyesters	8	5	20
Acid esters	1	7	20
Acid polyesters	2	5	20
Total esters	**67**	**44**	**134**
Hydrocarbons	14	10	66
Free acids	12	8	10
Alcohols	1	5	?
Others	6	7	?
Total	**100**	**74**	**at least 210**

Composition

Beeswax is an extremely complex material containing over 300 different substances.[47] It consists mainly of esters of higher fatty acids and alcohols. Apart from esters, beeswax contains small quantities of hydrocarbons, acids and other substances (see table 1). In addition, approximately 50 aroma components have been identified.[22] The wax produced by different subspecies of *Apis mellifera* have the same composition, but some of the components are in different proportions.[5,13]

The composition of the wax differs between *Apis florea* and *Apis cerana*, and also from *Apis mellifera* wax.[13] Further detailed information on composition and properties of beeswax can be found in other publications.[6,31,35]

Quality control

Quality criteria

Beeswax is a natural product and no additives are permitted. Examination of the sensory characteristics (e.g. odour and colour) of beeswax allows a simple, quick quality check. Wax adulteration can be detected by different methods. Determination of sensory and physicochemical characteristics according to the *Pharmacopoeia*[3] (table 2) does not guarantee that the wax has not been adulterated, although in some cases they can give hints on possible adulteration. Today adulteration is mostly detected by gas chromatography (GC) or liquid chromatography to determine the components of the wax.[1,12,14,33,34,42,45] In the special case of adulteration with carnauba wax, a simple biological test can be also used.[4]

TABLE 2. Properties and quality criteria for beeswax according to the *Pharmacopoeia*.[3]

Parameter	Requirements
Sensory and physical characteristics	
Colour	yellow to yellow-brown
Upon breakage*	fine-granular, blunt, not crystalline
Odour	honey-like
Consistency*	Should not stick upon cutting
Melting point	61–65 °C
Density	0.950–0.965
Refractive index (at 75 °C)	1.440–1.445
Physicochemical properties	
Acidic number	18–23
Esterification number	70–80
Peroxide number	at least 8
Authenticity*	no adulterants
Contamination*	according to requirements or as low as possible

* excepted

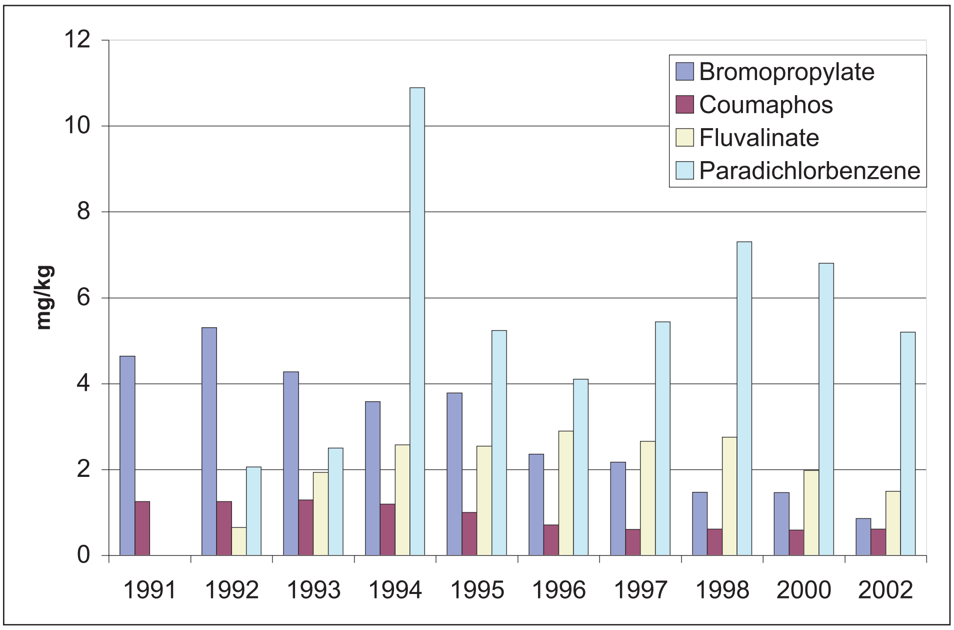

FIG. 1. Monitoring of organic pollutants from beekeeping in Swiss beeswax. Representative samples of all wax produced in Switzerland was taken in the frame of a long-term study.[8]

The main contaminants of beeswax are chemicals used in beekeeping, while contamination from the environment seems to be less important.[7] Traces of organic pollutants have been found in beeswax.[2,21,23,32] Only traces of some pesticides were detected in a recent study on Swiss beeswax, where 69 common pesticides were examined.[11] Beeswax is contaminated mainly by lipophylic (fat soluble) acaricides in the range between 0.5 and 10 mg/kg.[8,44,49] A long-term monitoring study on Swiss beeswax examining all major organic contaminants, originating from beekeeping, has been carried out in our research centre since 1991 (fig. 1) In this study the long-term behaviour of synthetic substances used in beekeeping has been studied. The investigations show that the acaricide concentration in wax increases with increasing number of acaricide applications (e.g. of tau-fluvalinate) but decreases very slowly after acaricide use has ceased (e.g. bromopropylate). The half-life of an acaricide in beeswax, i.e. the time which will elapse for disappearance of the acaricide depending on the initial acaricide concentration, is about five years. Let us take as an example bromopropoylate: this acaricide is no longer in use in Switzerland since 1991, when new and more efficient acaricides like coumaphos and tau-fluvalinate were introduced on the market. Bromopropylate levels are diminishing steadily and will probably drop below the present limit of detection of 0.1 mg/kg after 2006.

As beeswax is used in cosmetics and pharmaceuticals, it should contain minimal amounts of contaminants. Unfortunately, there are no maximum residue limits (MRLs) for contaminants. For beeswax used in

FIG. 2. Wax angels make music by candlelight. Wax was used for many different purposes since ancient times. Today, making candles and figures out of beeswax is also very popular.

organic beekeeping in countries like Italy, Germany and Switzerland, MRLs of between 0.1 and 1 mg/kg for each acaricide have been proposed. These limits will guarantee that no measurable amounts of acaricides can diffuse from wax into honey.

Other fat-soluble substances used in beekeeping, such as *p*-dichlorobenzene, used against wax moths, can also contaminate beeswax (fig. 1).[9,48]

Another potential problem for the quality of beeswax used for beekeeping is the presence of American foulbrood (AFB) (*Penibacillus larvae larvae*) spores. Indeed, only heating of wax at 140 °C for 30 minutes will destroy the spores.[38] On the other hand, experiments have shown, that only very high contamination with spores might cause AFB.[41] In this work it was concluded, that normal contamination of commercial beeswax with *P. l. larvae* spores is not likely to cause AFB.

Preventive measures against contamination

Acaricides cannot be removed from wax because of their different chemical structure. The best strategy to improve wax quality is to use non-toxic natural organic acids in alternative varroa control.[29] It has been found that residues of synthetic acaricides can be reduced rapidly below the detection limits by exchanging the old contaminated foundations by residue free ones.[29] The contaminants, used for the control of wax moths (e.g. *p*-dichlorobenzene and naphthaline) can be avoided by using alternative control measures:[15]

- Storage of combs in a cool bright place at 5–15 °C with good air circulation.
- Repeated storage for more than 10 hours each time in a freezer.
- Use of non-toxic chemicals like sulfur, acetic or formic acid or application of *Bacillus thuringiensis* for successful wax moth control.

Economy

Nearly all commercial wax is produced by *Apis mellifera*, mainly *A. m. ligustica*. It is difficult to obtain reliable figures on wax production, as the greater part of beeswax is used in beekeeping for producing comb foundation. Of all bee products the economic importance of beeswax is second after that of honey. It is estimated that its production is about 1.5 to 2.5% of that of honey.[19] Thus, based on FAO Comtrade statistics, 1.19 million tonnes of honey were produced in 1991, and between 17 850 to 29 750 tonnes of wax were produced during the same period.[30] The same source cites the following figures on the trade of beeswax:

'In world trade statistics beeswax is grouped with other insect waxes. Nevertheless, beeswax is a major component of insect waxes, and the trade value can be safely assumed to be that of beeswax. Based on the information derived from the COMTRADE database, total value of the insect waxes traded internationally during 1988, 1989, 1990 and 1991 was 23.63, 23.27, 26.08 and 23.35 million US$, respectively. During 1992, major exporting countries were China (14.9%), United Republic of Tanzania (11.4%), Germany (11.1%), Canada (7.0%), the Netherlands (6.3%), Brazil (6.1%), Japan (5.7%), USA (4.8%) and Ethiopia (3.7%); collectively accounting for 71% of the total trade volume in insect waxes. Australia, France, Chile, UK, Dominion Republic and New Zealand were some of the minor origins.'

Comtrade statistics have mixed refined/bleached wax and raw wax production data. However, there are no other statistical sources which do this separation. The major exporting countries of raw beeswax for the same year were: China, Tanzania, Canada, Brazil and Ethiopia, together with Australia, France, Chile, New Zealand and the Central African Republic.[40] In the main, beeswax exported from Germany, the Netherlands, UK and USA was re-exported refined/bleached wax, produced out of the raw wax of the above countries.[40] The USA is a major raw beeswax supplier, consuming most of its own production, being also a worldwide supplier of refined wax.[40]

According to Comtrade statistics the price per tonne of beeswax in 1991 was from US$3300 to US$3600. [30] There are no new figures on wax trade. Other earlier figures on wax production and trade are given elsewhere.[19] As a major part of the commercial beeswax is now contaminated by acaricides,[44] there is an increased need on the market for residue-free beeswax.

Uses

Besides its use for foundation, which is probably the main use, wax is also used for the following purposes: cosmetics (25–30%), pharmaceutical products (25–30%), candles (20%) and other purposes (10–20%).[19]

Beeswax is often preserved in archaeological deposits and so there is plenty of evidence for its early use.[18] Beeswax candles have been used by early mankind in religious ceremonies. Beeswax figures have survived in royal Egyptian tombs dating from 3400 BC.[19] Throughout history beeswax has been used in commerce and business as a document seal. One of the most important uses of beeswax is in *cire-perdue*, or lost-wax casting.[18] This technique is very old and was known in different high cultures such as in Sumeria, India, China and Egypt. Many of the world's most famous statues were produced using the lost-wax casting process. Beeswax is used in batik art. The word *batik* is of

Indonesian origin, where batik art was invented. Beeswax has other minor uses: used as an ingredient in the restoration of pictures, polish materials, chewing gum, nursery grafting, musical instruments etc. Beeswax is added to paints, polish, cosmetics and is used for coating food and tablets.

In cosmetics beeswax is used as an ingredient of creams, ointments and lotions. It has antibacterial properties[36] and when applied to the skin improves its elasticity and makes it look fresh and smooth. Warm beeswax has excellent warming properties when applied against inflammation of muscles, nerves and joints. The use of beeswax in apitherapy is dealt with in detail elsewhere.[16,39]

More details concerning the different uses of beeswax, as well as of its importance in use, trade and history are given elsewhere.[17,19,24,25,37]

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STEFAN BOGDANOV

Agroscope Liebefeld Posieux, Swiss Bee Research Centre, Liebefeld, 3003 Bern, Switzerland

stefan.bogdanov@alp.admin.ch