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REVIEW ARTICLE

# Challenges and perspectives for beekeeping in Ethiopia. A review

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## Abstract

The honey bee is an important fruit and vegetable pollinator and a producer of honey and other hive products. Beekeeping is a sustainable and high-potential activity for local communities and especially for the rural poor to gain additional income through non-timber forest products, does not require much land or high starting costs, maintains biodiversity and increases crop yields. Ethiopia is one of the top ten honey and beeswax producers in the world, but plays only a minor role in the international honey trade. Unlike large-scale beekeepers using modern techniques found in most leading honey-producing countries, the majority of Ethiopian beekeepers are small-scale producers practicing traditional beekeeping. In this article, we summarize the knowledge on Ethiopian beekeeping, honey bees, honey bee pests, marketing strategies, cultural aspects and major challenges of beekeeping. Furthermore, we used FAOSTAT data to calculate a pollination gap in order to draw the attention of stakeholders and decision-makers to bees and their importance in pollination and sustainable rural development. In regard to forage, we compiled 590 bee forage plants and their flowering times as a supplement to the article. This review outlines the following major points: (1) Ethiopia is a top honey and beeswax producer mainly for the domestic market; (2) Equipment for traditional beekeeping is easily accessible but brings disadvantages (gender gap, limitations in hive management and lower honey yield), while transitional and modern systems require certain beekeeping skills and higher starting costs; (3) Colony numbers increased by 72% from 1993 to 2018 and crop areas needing pollination by 150%; (4) Honey yield per hive and number of beehives managed per area of bee-pollinated crops increased by 20% and 28%, respectively; (5) Pesticide use has been increasing and there is a lack in pesticide use education. Recommendations to realize Ethiopia's tremendous apicultural potential are discussed.

**Keywords** Honey bee · Beekeeping · Honey · Beeswax · Rural development · Non-timber forest products · Pollination

**Contents**



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## 1 Introduction

Ethiopia is a landlocked country in sub-Saharan Africa and belongs together with Djibouti, Eritrea and Somalia to the Horn of Africa. In 2018, the population size of Ethiopia reached 109.2 million people distributed over an area of 1.1 million km$^2$. From those, 79.2% live in rural areas, while the rest is situated in urban regions (FAOSTAT 2020). The topography of the country is diverse and, associated with the land-structure and depending on the literature source, the land is dispatched into 3–5 climate zones (Bekele-Tesemma 2007; Gangwar et al. 2010; Gupta et al. 2014). Ethiopia has a long history and many traditions which are deeply rooted in the culture of the local population. Especially in rural areas, traditional medicine and traditional agricultural activities are practiced in everyday life (Bantie et al. 2019).

Agriculture plays a key role in the country. About 12 million smallholder farming households produce 95% of all agricultural goods (FAO 2020). In 2000, the agricultural sector employed 76.4% of the working population gradually declining to 66.2%

in 2019 (UNDP 2019). This decline is accompanied by climate change (droughts), rural exodus and the change in policies and livelihood. Many NGOs work together with the government to improve the lives of the population. Although Ethiopia still ranks 173rd out of 189 countries on the UN Human Development Index (HDI), more and more people gain access to education and communication tools such as phones or Internet (UNDP 2019). Development and modernization thus also reached fields that have been dominated by traditional techniques, such as beekeeping (Yirga and Teferi 2010). Traditional beekeeping belongs to the oldest agricultural activities in Ethiopia and still is a major integral component in today's agricultural economy of the country (Fikru 2015).

These days, it is well known that beekeeping is a sustainable and high potential activity for local communities to gain additional income through non-timber forest products (Bareke et al. 2018; Fikadu 2019). Beekeeping does not require much land or high starting costs, and people from child to advanced age are able to perform this activity without advanced skills (Bradbear 2009; ICIPE 2013). Bees do not only positively contribute to income gain by their products (honey, pollen, beeswax, propolis, royal jelly), they are also important insect pollinators and increase yields of agricultural products, and maintain biodiversity (Archer et al. 2014; Carvalheiro et al. 2011; Ollerton et al. 2011; Reilly et al. 2020).

The aim of this review is to give an overview of beekeeping activities in Ethiopia and to highlight once again the importance of bees as pollinators as well as discussing their potential to improve the livelihood of people with poor income. Similar to the article of Al Naggar et al. (2018), crops that need insect pollination services were evaluated and a potential pollination gap was assessed to draw attention of stakeholders and decision makers to bees and their importance in the environment. In the past decade, numerous articles engaging the Ethiopian honey bee sector were published in a variety of journals. However, the publications often do not meet global publication standards and the corresponding journals are often of lower professionalism. For this article, we tried to choose the most reliable publications including "grey" literature to shed light on the tremendous research activities taking place in Ethiopia. Further, we used FAOSTAT, the publicly available database of the Food and Agriculture Organization of the United Nations (FAO) for all our calculations and graphs. Even though big apicultural players such as China, the USA, EU, New Zealand and India dominate the global honey and beeswax market, Ethiopia is considered to be an important beekeeping country with high potential. Further, the various forms of beekeeping and the long intra-cultural tradition of beekeeping are worth putting in perspective (Fig. 1).

## 2 Beekeeping in Ethiopia

Documents of hieroglyphs in Egypt indicate that basket (skep) beekeeping in Ethiopia has been practiced for approximately 5000 years. They refer to honey and beeswax trading activities with the realm Abyssinia, the exonym of Ethiopia (Gezahegne 2001). Today, the country is the number one honey and beeswax producer in Africa and belongs to the top ten worldwide (Adeday et al. 2012; FAOSTAT 2020). For beekeeping activities, mainly the autochthonous Western honey bee *Apis mellifera* is used and Ethiopian beekeepers do not choose a specific subspecies for beekeeping, instead they use the locally available strains. Bee breeding programs do not exist and beekeepers acquire new colonies from either local markets, from the wild or from colony multiplication (Gebretinsae and Tesfay 2014; Hailu and Tadesse 2016). Further, there are no official reports of honey bee colony or queen imports from other countries or continents, even though this cannot be ruled out completely. Classification and geographical distribution of Ethiopian honey bees have been intensively discussed within the research community but methodological variations have been leading into contrasting results and opinions. While some recently published articles based on mitochondrial DNA analysis described the Ethiopian honey bees, with their evolutionary lineage Y, to be genetically distinct from other *A. mellifera* subspecies in neighbouring geographic areas (Boardman et al. 2020; Franck et al. 2001; Tihelka et al. 2020), Hailu et al. (2020) reported of maternal lineage O to be present in northern Ethiopia. Morphometric analysis investigating present subspecies was also not in agreement with each other (Amssalu et al. 2004; Hailu et al. 2021; Meixner et al. 2011; Nuru et al. 2002a; Radloff and Hepburn 1997; Ruttner 1988). Based on the methods used, up to three *A. mellifera* subspecies were described (*A. m. jemenitica*, *A. m. scutellata*, *A. m. monticola*). However, two more, namely *A. m. bandasii* and *A. m woyi-gambell*, were also mentioned in the literature (Amssalu et al. 2004; Radloff and Hepburn 1997) — today, both are not considered distinct subspecies anymore. In contrast, Meixner et al. (2011) grouped all Ethiopian honey bees into a single subspecies — *A. m. simensis*. They further found morphometric variations of *A. m. simensis* in relation to altitude. This is in agreement with a recent study by Hailu et al. (2021), who performed morphometrics, as well as genetic analysis on Ethiopian bee samples. They concluded that Ethiopian honey bees differ from populations of neighbouring countries and also identified rather high gene flow and morphometric variations across three elevation levels triggered by anthropogenic influence, especially through colony trading. The mitochondrial genome of *A. m. simensis* was recently sequenced by Boardman et al. (2020). Unfortunately, there is no sufficient data to methodically examine whether *A. m. simensis* is native or endemic to Ethiopia. The dwarf honey bee, *Apis florea*, is definitely not native to

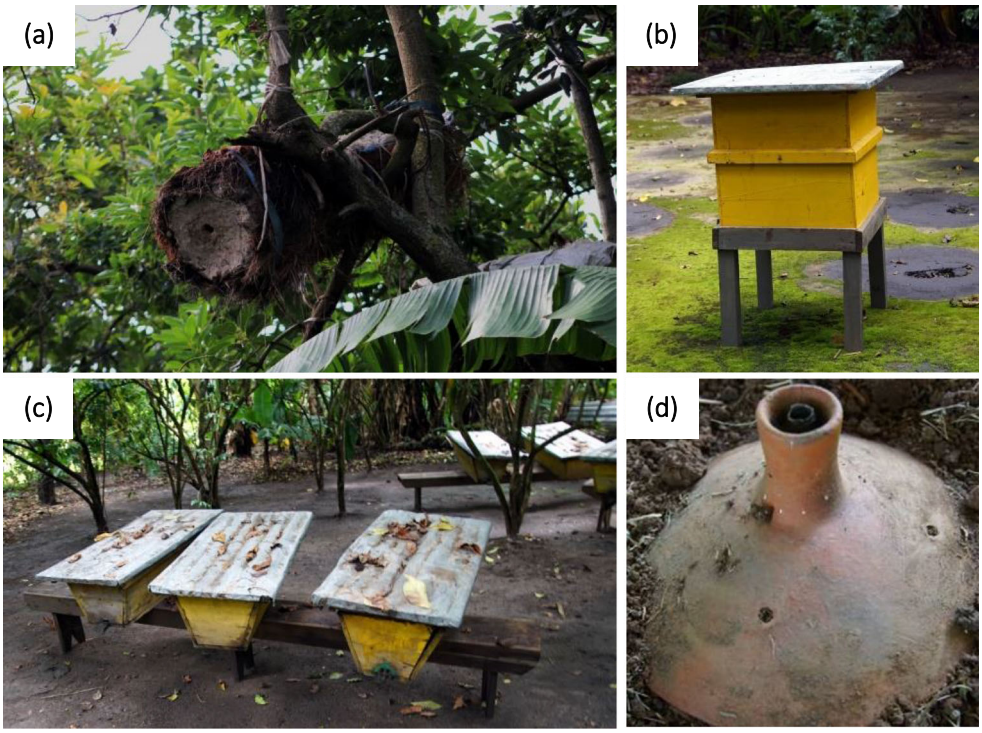


**Fig. 1** **a** Traditional log hive for *A. mellifera* bees, **b** modern movable frame hive, **c** transitional Kenyan top bar hive and **d** clay pot hive for stingless bees. Photos by Sascha Fiedler.

Ethiopia but started to spread in the northern areas of the country (Pauly and Zewdu 2013; Zewdu et al. 2016). At the moment, we do not know if *A. florea* is actively fought or distributed, or if it is used for beekeeping activities (Bezabih et al. 2014).

In addition to keeping honey bees, also meliponiculture (beekeeping with stingless bees) is practiced in Ethiopia. Here, we must differentiate between beekeeping and hunting wild colonies of stingless bees. For the latter, experts (e.g. shepherds) observe stingless bees on flowers, follow them to their nesting site and mark the entrance to demonstrate ownership of the nest. When the time is considered right, the experts carefully harvest the honey from the nests situated in 1-m depth (Fichtl and Adi 1994; note that the latter author is sometimes spelled "Addi", "Admasu" or "Admassu" in literature databases. A fact often true also for other Ethiopian authors). The diversity of Meliponini in Ethiopia was investigated in 2013 by Pauly and Zewdu. They found six species of stingless bees: *Meliponula beccarii* (Gribodo, 1879), *Liotrigona bottegoi* (Magretti, 1895), *L. baleensis* sp. nov., *Hypotrigona gribodoi* (Magretti, 1884), *H. ruspolii* (Magretti, 1898), and *Plebeina armata* (Magretti 1895). For the continent Africa, six genera comprising 19 stingless bee species were described (Eardley 2004). As differentiation between species is difficult, they are often summarized as genus *Trigona* in Ethiopian literature sources. *Trigona* spp. is present at altitudes up to 2300 m a.s.l. and honey won from *Trigona* colonies is called *tazma,* which is often used as traditional medicine (Fichtl and Adi 1994). Little has been published on meliponiculture in Ethiopia, but exclusively local materials are used for housing stingless bees (Fig. 1d). Those include mud, dung, clay pots or simple wooden constructions. Holeta Bee Research Center, an institution focusing on honey bee research in Ethiopia, is currently running several experiments on stingless beekeeping and results should be published in the near future. Other African countries have been investigating stingless bees for a longer period of time — stingless beekeeping manuals for the public are already available (Kwapong et al. 2010).

A number of questions regarding the Ethiopian bee and honey bee diversity remain to be addressed including further research on taxonomy. This would enable the understanding of differences in the biology, behavior, geographical distribution and the performances of Ethiopian bees. There are no established bee breeding programs in the country and based on the sheer number of colonies, we conclude that there is no urgent need for a bee breeding program so far. Nevertheless, if the beekeeping sector reaches a more developed stage, selective breeding for better performance of bees is recommended to boost beekeeping by making full use of the country's apicultural potential. How to successfully establish sustainable breeding programs and which factors and infrastructure are needed was for example reported by Zakour and Bienefeld (2014) and Uzunov et al. (2017).

The annual honey production was estimated to 50,000 tons in 2018 (FAOSTAT 2020), a similar number was announced by CSA (Central Statistics Agency) Ethiopia (2019; Table 1). A report by the Ministry of Agriculture Ethiopia (MoA and

**Table 1** CSA (Central Statistics Agency) Ethiopia data from 2016/17, 2017/18 and 2018/19. Number of beehives [n], types of beehive systems used and corresponding honey production rates in [tons] and [kg/hive] are presented. *For critical evaluation of these values, see text. Data source: CSA (https://www.statsethiopia.gov.et/our-survey-reports/).

| | 2016/17 | 2017/18 | 2018/19 |
|---|---|---|---|
| Beehives [n] | | | |
| All beehives | 6,189,329 | 6,523,969 | 7,075,188 |
| Traditional hives | 5,902,624 | 6,327,197 | 6,794,424 |
| Transitional hives | 80,832 | 69,399 | 80,164 |
| Modern hives | 205,873 | 127,373 | 200,600 |
| Honey production [tons] | | | |
| All beehives | 47,706 | 66,222 | 58,588 |
| Traditional hives | 42,928 | 63,798 | 54,368 |
| Transitional hives | 2,037* | 497 | 952 |
| Modern hives | 2,741 | 1,926 | 3,269 |
| Honey production per hive [kg/hive] | | | |
| All beehives | 8 | 10 | 8 |
| Traditional hives | 7 | 10 | 8 |
| Transitional hives | 25* | 7 | 12 |
| Modern hives | 13 | 15 | 16 |

ILRI 2013) estimated the actual potential of the whole Ethiopian apicultural sector to be about ten times higher with potentially ten times more beekeepers, hived colonies and consequently honey harvest. No data is given on the exact number of beekeepers, but it is estimated to be more than one million (0.95% of total population; Gupta et al. 2014), managing around 6 million *A. mellifera* bee colonies (Beyene et al. 2016; FAO 2020; Yirga and Teferi 2010). Putting this data into context with the total population and the total country area, Ethiopia has 0.91 beekeepers/km$^2$, 6.01 colonies per beekeeper and 5.60 colonies/km$^2$. Compared to big apicultural players such as Europe, the overall density of managed hives is slightly higher in Ethiopia, but the mean number of hives per beekeeper is 3.6 times higher in Europe (Brodschneider et al. 2019; Chauzat et al. 2013). Here, it has to be mentioned that Ethiopia holds a huge reservoir of wild bee colonies. It has been estimated that the country houses a total of 10 million *A. mellifera* colonies (9.1 colonies/km$^2$) and among those 60% are hived (MoARD 2007). FAOSTAT (2020) recorded a steady increase of managed beehives in Ethiopia over the years 1993–2018 (Fig. 2), which was also observed for the rest of the African continent (Moritz and Erler 2016). Accompanied with that, the total honey production also increased during the observed time period. Nevertheless, the honey yield per hive has not appreciably improved in the same time period (Fig. 2). This indicates that the majority of the beekeeper population in Ethiopia still practices traditional beekeeping, which was also reported by CSA in 2019. They found that in 2018/19 96.0% of beehives comprised traditional systems. The honey harvest from traditional hives is lower than from transitional or modern hive systems, which will be discussed in the next section (Beyene et al. 2016; CSA 2019; Gemechis 2016; Yirga and Teferi 2010). The ongoing transition to modern hives in the past 3 to 4 years is not directly reflected by increased honey yields per hive (Fig. 2).

## 3 Traditional vs modern beekeeping

Traditional beekeeping is practiced with hives constructed from natural materials from the surrounding areas (MoARD 2007; Sahle et al. 2018). Often, they are cylindrical single chamber hives, which are made of easily accessible materials such as wood, clay, straw, bamboo or mud (Fig. 1). The practices used for traditional beekeeping are manifold and follow the area specific culture. For example, in southwestern Ethiopia, it is common to hang log hives into trees. Only males are involved in this forest beekeeping activity (Awraris et al. 2012; Kenesa 2018). Reasons why women do not participate have mostly cultural origins and physical motives. The hives need to be hung on 10-m-high branches of trees situated in dense forests. Climbing trees with the heavy log hives requires a certain physical strength and special skills. The work is carried out during night and is considered to be labour intense and dangerous and the beekeepers often stay in the woods for several days to maintain and harvest the hives. It is not forbidden for women to join those trips, but they prefer to not join for safety reasons and other cultural duties such as household activities (Shackleton et al. 2011; Sebsib and Yibrah 2018). Though, women are not totally excluded: they are responsible for product processing (e.g. *tej* brewing) or marketing of the bee products (Kebede et al. 2018).

Another form of traditional beekeeping is mostly practiced in the central, northern and eastern areas of Ethiopia and is called backyard beekeeping, where beekeepers use special backyard systems in safeguarded areas for honey bees. The systems are situated in the houses of the beekeepers, under the roof of the houses or other structures serving as weather protection for the hives (Yirga et al. 2012). This form of beekeeping is considered to have more potential, as it is safer than forest beekeeping. Further, it significantly contributes to the family's income without the requirement of own farming land (Sebsib and Yibrah 2018; Serda et al. 2015). Backyard beekeeping can not only be conducted with traditional, but also with transitional or modern beehives. It is often not a one-person activity, instead the whole family including women participate. Keeping bees next to the households allows women to play a bigger role in either assisting their husbands, or in starting their own apiary to become economically independent and increase self-esteem (Olana and Demrew 2018). Assisting

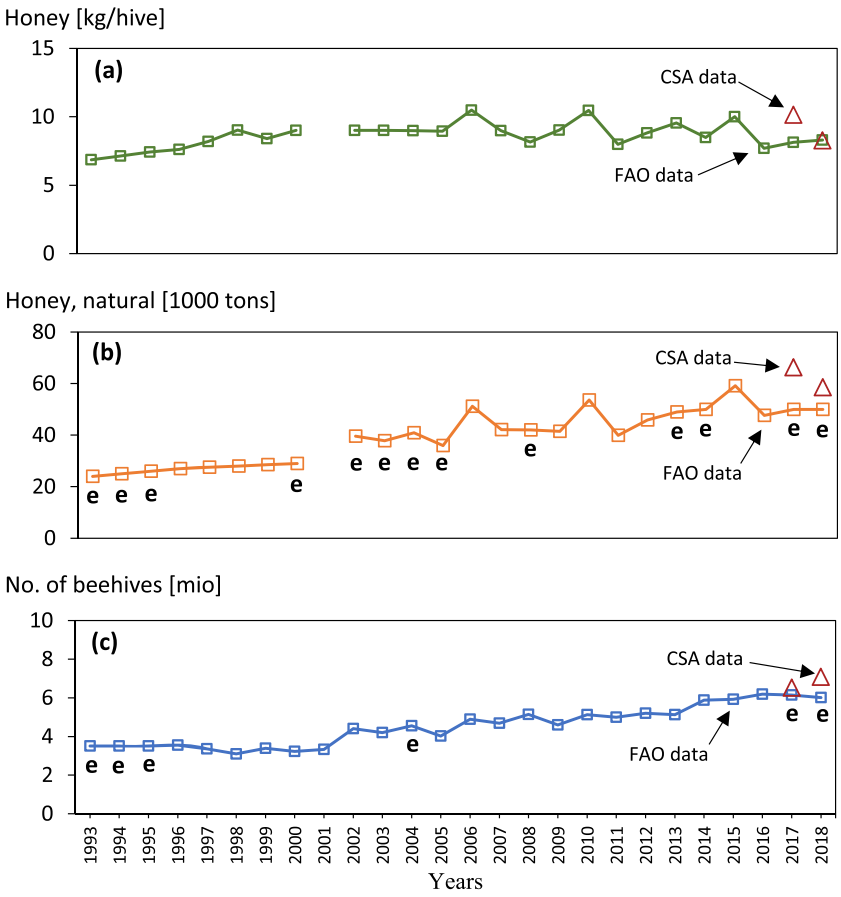


**Fig. 2** **a** Honey yield per hive [kg/hive], **b** annual harvest of unprocessed honey [1000 tons] and **c** number of beehives [mio] from 1993 to 2018 in Ethiopia. Data source either FAO (www.fao.org/faostat) or CSA (Central Statistics Agency) Ethiopia (https://www.statsethiopia.gov.et/). °Data was estimated by the FAO.

roles typically include clearing the nearby spaces of the stocked hives, cleaning of the hives with steam (no details given here) and marketing of the harvested bee products.

Traditional hive systems have several disadvantages such as unsustainability or lower honey productivity (Beyene et al. 2016; CSA 2019; Gemechis 2016). The hive is not manageable at all and honey harvest is always destructive for the nest and the colony. There are no movable frames in the hives and the natural comb-construction is severely damaged when the hive is opened. Internal inspection, providing feeding systems or swarm control is not possible (Fikru 2015; Sebsib and Yibrah 2018). The honey yield of traditional hive systems has been demonstrated to be lower than those of transitional or modern systems despite the same availability of resources within the flight radius (Beyene et al. 2016; Gemechis 2016; Girma et al. 2008). In Europe, where modern hive systems are dominant, the average honey yield per hive in 2018 ranged from 9 to 47 kg per hive (FAOSTAT 2020). While 5–8 kg of honey can be expected from traditional Ethiopian hives, the average honey yield of transitional and modern hives ranges from 15 to 20 kg (Beyene et al. 2016; Gemechis 2016; MoARD 2007; Yirga and Teferi 2010). Based on the past 26 years, the Ethiopian average was 8.3 kg of honey per hive (Fig. 2; FAOSTAT 2020). Even though publications on honey production of neighbouring African countries are scarce, we found evidence of annual honey yields per hive of 13.0 kg (modern hives) for Sudan (n = 96 surveyed beekeepers; Elzaki and Tian 2020), and 4.4 kg for Kenya (n = 91 surveyed beekeepers; Carroll and Kinsella 2013). Numbers for whole Africa based on the FAOSTAT data suggest an average of 10.2 kg per hive in the past 26 years. Annual Ethiopian honey production per hive is 19% below the continent's average.

Honey gained from traditional hives is often a mixture of wax, bee parts, honey and pollen and is therefore called "crude honey" (Awraris et al. 2012; Fichtl and Adi 1994). High moisture levels are common in all parts of the country. Gemechis (2016) reports water contents of 15.3 to 30.4% from mostly, but not exclusively, traditional hives. Nevertheless, physico-chemical analysis of Ethiopian honey samples attested them a good quality even though increased water insoluble solid contents were found in honey samples from traditional hives (Adugna et al. 2020; Belay et al. 2013; Getu and Birhan 2014; Mesele 2020). Next to management skills, the high water contents are also attributed to climate. Besides many disadvantages, traditional hive systems also have positive aspects. The beekeepers who use them do not need special skills, the starting costs are low because locally available materials are often cheap and easily accessible, no management means less time-effort, less to no equipment is needed and bees kept in such systems produce more beeswax and propolis which

can be traded at higher prices per kg compared to honey (Fikru 2015; Girma et al. 2008; Nuru et al. 2002b; Serda et al. 2015). Despite the higher honey quantity of transitional and modern systems, these mentioned benefits may be the reason why traditional beehives remain dominant in Ethiopia (CSA 2019). The government and NGOs have recognized the drawbacks of traditional systems and ever since started to promote transitional and modern beehives, which are placed on stands, often situated near the homes of the beekeepers (Alebachew and Eshetie 2019). The promotion of modern hive-systems alone is not sufficient to improve the beekeeping situation of a beekeeper. Survey-based studies found out that many young beekeeping groups using modern systems do not have access to beekeeping equipment and if so, they often do not know how to use or maintain them, resulting in untapped potential (Alebachew and Eshetie 2019). Nevertheless, through the easier access to modern hives, beekeeping got especially more attractive for young people and women (Abebe 2007).

Transitional (intermediate) systems are in between of traditional and modern hives and have been promoted by GOs and NGOs since 1978 (Beyene et al. 2016; Yirga and Teferi 2010). They are manageable, increase the safety of beekeepers who do not need to climb on trees anymore and promise higher honey yields than traditional hives (Fig. 1; Table 1). The most popular types are the Kenyan top bar hive and the "*Chefeka*" hive (Gemechis 2016). The latter is exclusively made of locally available materials (e.g. bamboo), making it more affordable than other top-bar hive types.

Modern hives are characterized by movable frames and their high management potential including honey stored in supers. Depending on the colony's activity and status, the modern hive persists of up to four boxes. Modern beekeeping is mostly practiced in the southwestern and in the central highland areas of Ethiopia. Popular systems include Zander, Langstroth and Dadant (Gupta et al. 2014; Hailemichael 2018). Next to beekeeping, "honey hunting" is common due to the presence of feral bee colonies in Ethiopia (Fichtl and Adi 1994; Gemechis 2016). Similar to hunting stingless bee colonies, people look for wild honey bee nests and collect their honey stores. Honey hunting is often performed in forest dominated areas and is not restricted to own land. Still, as this activity involves climbing trees, often at night, it is considered to be dangerous. Further, through the massive manipulation, the bee colonies get severely disturbed and damaged (Crane 1999).

In 2016/17, 95.4% of all hives in the country were traditional, while 1.3% were transitional and 3.3% were modern hive systems, respectively. Two years later, the total number of beehives increased by 14.3% to 7.1 million hives in the country. From those, 96.0% were traditional, 1.1% were transitional and 2.8% were modern systems (Table 1; CSA 2017, 2019). When comparing the total amount of harvested honey from the three systems for the same time period, honey production per hive increased by 1 kg and 3 kg for traditional and modern systems, respectively. A noticeable decrease in productivity occurs in transitional hives with minus 13 kg, indicating irregularities in the 2016/17 estimations for this hive type (Table 1; CSA 2017, 2019).

## 4 Honey bee management and bee health

African honey bees are more aggressive than European or Asian honey bees (Kastberger et al. 2009). For safety reasons, Ethiopian beekeepers open their hives mostly when the sun has already set to protect themselves from stings (Shackleton et al. 2011). Nevertheless, climbing trees during the night to reach traditional hives is dangerous and complicated. Several survey-based studies reported that external hive inspection and cleaning of the apiary is far more common than internal hive inspection (Fikru et al. 2015; Kebede et al. 2018; Nuru et al. 2002a; Sebsib and Yibrah 2018; Serda et al. 2015). Latter is done by 23–33% of respondents and differs greatly between regions (Beyene 2015; Fikru 2015). Reasons for not inspecting the hives internally are the fear of bee stings, possible triggering of absconding behaviour and lack of time and knowledge (Sebsib and Yibrah 2018). Internal inspection of traditional hive types is not practiced as it would be accompanied by a destruction of the bees' nest (Kerealem et al. 2009).

Regional differences are also found in supplementary feeding of bees in times of food shortage or droughts: while 3.1% of respondents feed their bees in the Haramaya District (Serda et al. 2015), up to 60% provide supplementary carbohydrates (e.g. sugar syrup, honey solutions, flour) and proteins (e.g. chickpeas or peas) in the western Amhara region. Traditionally homemade recipes are summarized in Fichtl and Adi (1994), Assemu et al. (2013) or Solomon (2009). Exceptional supplementary food sources, especially provided for mineral uptake in some rural regions of Ethiopia, were also described by Fichtl and Adi (1994). They reported the use of "freshly slaughtered meat scraps" and "fresh animal blood". However, these substances are questionable due to the possible uptake of pathogens, which may be detectable in bee products, hygiene issues and suitability. Swarming prevention is not common, which could again be associated with traditional hives (Sebsib and Yibrah 2018). Other survey-based studies focusing on South-East and East Ethiopia reported that beekeepers cut parts of brood combs, remove queen cells, add supers, or provide empty hives to prevent reproductive swarming (Fikru et al. 2015; Solomon 2009). In contrast to the articles surveying the most common hive management techniques, recent research articles empirically demonstrated potential improvements in hive management. These range from feeding regimes to cope with dearth seasons, migratory beekeeping (Kumsa et al. 2020), methods to increase propolis production (Nuru et al. 2002b), to maintain colonies with two

queens at least transiently (Wakjira et al. 2020). While techniques for multiple queen colonies with other *A. mellifera* subspecies were already developed (Zheng et al. 2009a, b), for the Ethiopian highlands, Wakjira et al. (2020) for the first time investigated this method to increase colony development, food stores and profits mostly by reduced beeswax, feeding and labour costs.

Studies on honey bee health are rare and mainly deal with predators and pests visible to the human eye. Thus, organisms like *Aethina tumida* (small hive beetle), *Braula coeca* (bee louse), *Galleria mellonella* and *Achroia grisella* (wax moths), *Mellivora capensis* (honey badger), *Merops* spp. (bee eater birds), or ants are frequently reported, compared to pests and pathogens like foulbrood causing bacteria, amoeba, viruses, *Nosema*, chalkbrood or mites (Begna 2014; Gebremedhn et al. 2020; Sebsib and Yibrah 2018; Teferi 2018). Studies on the prevalence of these diseases are recommended. *Varroa destructor* is a worldwide problem for honey bees and beekeepers, and in most of the western countries, colonies must be treated against *Varroa* regularly; otherwise, the colonies might be weakened or die (Noël et al. 2020). The situation is different in African honey bees. *V. destructor* and the tracheal mite *Acarapis woodi* are present in Ethiopia (Pirk et al. 2015), but no studies on colony losses linked to them are available. In fact, a study by Gebremedhn et al. (2019) indicated that observed Ethiopian (Tigray region) bee colonies had very low brood infestation levels. From 6727 analysed brood cells, only 133 mites were found and from those, only 18.8% were capable of reproducing, supporting our knowledge that African honey bees successfully cope with the varroa mite. African *A. mellifera* shows increased absconding behavior, higher aggressiveness and intense hygiene behaviour, compared to the European strains. Those traits in combination with a lower fertility of varroa mites in African bee colonies may be possible reasons for the higher tolerance (Nganso et al. 2017; Strauss et al. 2016). The lower significance of *Varroa* is also reflected by the beekeepers' behaviour. Ethiopian beekeepers do not consider varroa mites and tracheal mites as risk for their colonies, and hence they do not treat their bees to fight the mites (Mezgabu et al. 2016; Muli et al. 2014; Pirk et al. 2015). In fact, they do pay more attention to ants and wax moths, which affect Ethiopian bees more. In some regions, up to 44% of bee colonies suffer from severe ant attacks resulting in an estimated economic loss of 3.8 million Ethiopian Birr per year (108,000 USD; Yirga et al. 2012). Wax moth infestation on the other hand results in 56–75% of cases in colony absconding (Begna 2015; Pirk et al. 2015). Furthermore, wax moths are found to be vectors for viruses and are responsible for a decline not only in hived, but also in feral African honey bee populations (Kwadha et al. 2017). Strengthening infested colonies, removal of old combs and regular cleaning of the bottom board of the hives are considered methods to minimize the infestation with wax moths (Gebremeskel et al. 2015). Further, providing proper storage facilities for beeswax and other hive products is highly recommended (Ritter and Akratanakul 2006). When Ethiopian bees suffer from unfavourable environmental conditions, diseases or are attacked by enemies, they show absconding behaviour (Nurie 2020). In contrast to reproductive swarming, all bees leave their nests without their brood and food storage to start over at a new nesting site (Crane 1990). By appropriate hive management, the risk of absconding behaviour as well as parasite pressure decreases.

Not only wild organisms, but also human actions negatively impact honey bee health. As mentioned above, Ethiopia houses an estimated number of 10 million bee colonies, from which 60% are kept in hives. Even though honey bee markets exist, most of the beekeepers gather their new bee colonies from the natural resource pool (Gebretinsae and Tesfay 2014). First, we do not know how the number of feral colonies was estimated and second, no information is given on the impact of catching feral bee colonies on the overall bee population size in Ethiopia. At this point, we cannot make any statements regarding the health status of captured bees, or the actual number of wild bee colonies and their future development, but we assume that the uncontrolled intervention in the ecosystems has an impact. Another important factor influencing the health of hived and feral bee colonies is the use of pesticides in agriculture and gardens (ASSAf 2021; Henry et al. 2012; Tome et al. 2020). According to FAOSTAT (2020), the worldwide use of pesticides almost doubled from 2.3 million tons in 1990 to 4.1 million tons in 2018. In Ethiopia, this trend was also observed, with a tremendous increase from 242 tons (1993) to 4100 tons in 2017 (FAOSTAT 2020). Still, the amount is 88 times lower than it was for the whole European Union (362,421 tons in 2017). In Ethiopia, large-scale, as well as smallholder farmers have easy access to pesticides and especially among vegetable farmers, it is common to mix several products prior to the application (Fikadu 2020). As the application and exposure of pesticides carry risks for a variety of organisms, including honey bees and humans, the use should be restricted to trained farmers only.

## 5 Bee colony and bee product trade

Regular markets, where colonies are traded, were followed by Gebretinsae and Tesfay (2014). They monitored prices per colony from 1999 to 2010, with annual increases of approximately 12%. Common problems of colonies purchased from these markets include relatively great differences in colony strength and the absence of queens. Private institutions and NGOs counteract those issues by teaching how to rear queens with locally available materials (e.g. wax or bamboo).

About 90% of the honey production is sold either to collectors (near village/town markets), or the beekeepers

associate to form cooperatives for production and marketing to control and develop their businesses (Gemechis 2016). The remaining 10% are consumed by the beekeeping households (Serda et al. 2015). Local cooperatives often cannot compete with bigger companies as they do not underlie a quality controlling body and the lack of "good beekeeping practice" and proper collection, storage and transportation facilities contribute to the lower quality of the honey products (MoA and ILRI 2013). The collectors and the cooperatives sell the product to wholesalers, acting as distributors, in bigger cities and to local *tej* breweries. *Tej*, or honey wine, plays an important cultural role in Ethiopia and can be compared to mead. Up to 80% of the collected honey is used to produce the traditional beverage, the rest is sold as table honey (Gemechis 2016; SNV/Ethiopia 2005; Yirga and Teferi 2010). *Tej* breweries use crude honey for the *tej*-brewing and during the process, the beeswax is separated as a by-product with lower quality compared to other purification processes (Serda et al. 2015). The by-product is sold to beeswax collectors and exporters, which makes *tej*-houses important stakeholders for beeswax businesses (SNV/Ethiopia 2005). The worldwide beeswax market is with an estimated amount of 70,000 tons relatively small (FAOSTAT 2020). In 2018, most of the beeswax (16,000 tons with a value of 84.2 million USD) was exported to the EU and was mainly used for pharmaceutical and cosmetic purposes (Bradbear 2009; FAOSTAT 2020). Based on the export and import data retrieved from FAOSTAT, Ethiopia is considered to be a net-exporter country for beeswax and honey (Fig. 3; FAOSTAT 2020).

India with 25,770 tons, or 39.4% of global production, is the world's biggest beeswax producer, followed by Ethiopia with a production rate of 5694 tons, which equals 8.2% of the global production in 2018 (FAOSTAT 2020). This amount corresponds to 0.95 kg beeswax per year and hive. However, the annual potential was estimated ten times higher (50,000 tons; Negash and Greiling 2017; SNV/Ethiopia 2005; Wilson 2006). Figure 3 summarizes the development of beeswax exports. In 2008, the European Union authorized the import of honey and beeswax from Ethiopia which is accompanied by an increase of beeswax and honey exports in the following years. In 2018, the beeswax' export quantity was 275 tons from which 95% were traded to Europe and the UK, followed by the USA and Japan (FAOSTAT 2020). The steady increase in export rates was followed by a decline in beeswax and honey export quantities after 2015 and 2013, respectively. However, this trend cannot be properly explained. For beeswax, the reason may be the low quality, as adulteration with cheaper fats (e.g. animal fat, plant oil or paraffins) was reported (Gemechis 2014).

FAO estimated honey production to 50,000 tons in 2018, but the actual production potential is regarded to be 500,000 tons annually (MoA and ILRI 2013). Although the honey production rate was more or less stable over the past decade (Fig. 2), the honey export market suffered from a decline from 2013 on (Fig. 3). Reasons may include the struggling of local companies in gaining access to international markets due to increased domestic prices associated with high domestic consumption of table honey (Dong et al. 2016). In addition, limited availability or access to appropriate accredited laboratories forces the exporters to extra costs in order to get a quality certificate, which is required to access the global market. Further, nearly 80% of the honey produced in Ethiopia is so-called crude or unprocessed honey, primarily used for the local *tej* production. On top, informal honey trade from Ethiopia to Sudan is suspected to evade taxes. Studies by the Holeta Bee Research Center are planned to find out more about that topic. Processor and exporter companies complain over not meeting the required amounts of table honey and thus cannot fulfil their

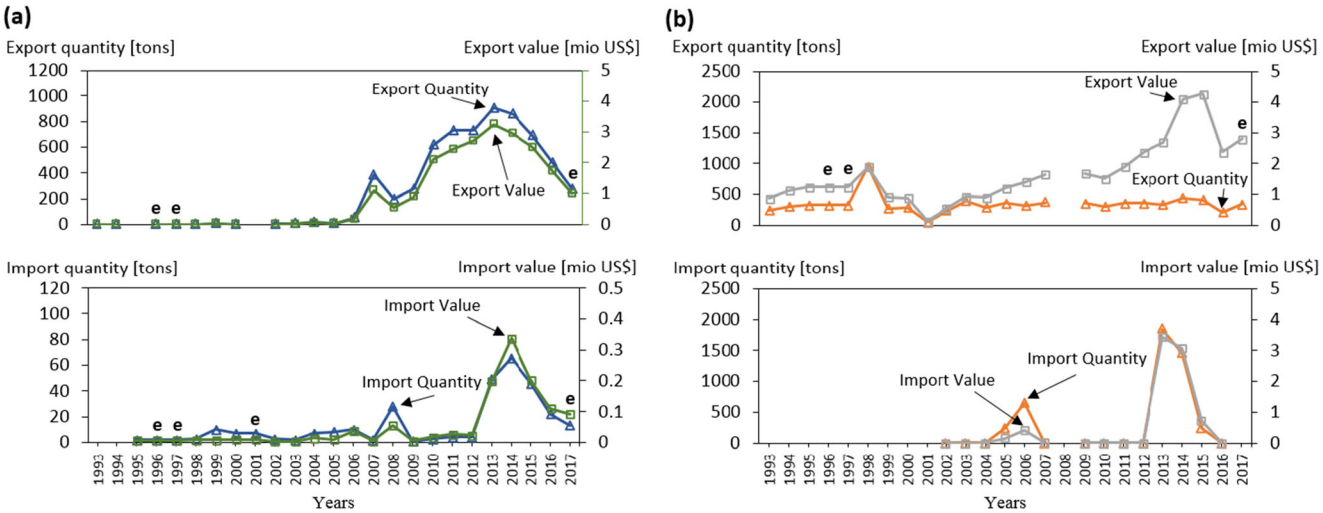


**Fig. 3** **a** Honey and **b** beeswax export and import data from 1993 to 2017. From 2008, the export of beeswax and honey into the European Union was possible. Quantity is given in [tons], value in [mio US$]. [e]Data was estimated by the FAO. Data source: FAO (www.fao.org/faostat).

international buyers' demands (Dong et al. 2016). For propolis, royal jelly and pollen, no production or trade data is available.

## 6 Forage and pollination

Ethiopia is a country with high floral diversity and bees, as well as other pollinators, benefit from hundreds of melliferous plants which are distributed over a variety of altitudes. Those variations in topography and the different climate zones complicate the development of flowering calendars. Although some attempts were made to address this issue for specific regions in Ethiopia (Degaga 2017; Wubie et al. 2014), the works by Fichtl and Adi (1994) and Admasu et al. (2014) remain the number one literature source for more than 590 melliferous plants. During our research, we compiled the information of these two literature sources to generate a visibly attractive scheme of a flowering calendar for Ethiopia, which is available as a supplement to this review (Table A.1). The following plants provide monofloral honey and are considered to be important forage plants for bees in Ethiopia: *Acacia*, *Becium grandiflorum*, *Croton macrostachyus*, *Eucalyptus globulus*, *Hypoestes*, *Leucas abyssinica*, *Schefflera abyssinica, Syzygium guineense* and *Vernonia amygdalina* (Belay et al. 2017; Bareke et al. 2020).

Animal pollination plays a key role in 78% of all plant species in temperate climate zones (Ollerton et al. 2011). A decline in bees and other pollinators impairs the harvest of many crops and consequently the income of farmers (Reilly et al. 2020). Especially in countries, where a great proportion of the human population depends on income from agriculture, the pollination of farming crops is crucial and keeping bees is particularly suitable for this job. Compared to many other pollinators, bees can be used systematically for places where their pollination service is desired. Further, people who provide the bees and maintain them, as well as farmers who provide the land, form a positive feedback-loop, as they both benefit from the beekeeping actions.

Some important crops including all grains do not depend on animal pollination, others also do not necessarily need pollination services but benefit from it. Latter include beans, potatoes, many other vegetables, a variety of fruits and coffee (Klein et al. 2007). Coffee is one of the most important Ethiopian export products with steadily increasing global demand. While in 1993, 180,000 tons of coffee were harvested on an area of 250,000 ha, farmers produced 470,000 tons of coffee from 686,000 ha land in 2018, which equals a yearly growth rate of 4% (FAOSTAT 2020). Adequate pollination through animals and especially through insects significantly contributes to plant reproduction, causes both, higher quantity and quality of fruits, and increases incomes of farmers, resulting in strengthening the whole country's economy (Abrol 2012; Corbet 1991; Westerkamp and Gottsberger 2000; Williams 1994).

Crop production and agricultural areas in Ethiopia increased from 1993 to 2012 but growth slowed down ever since (Fig. 4). As mentioned before, the number of people who work in agriculture decreased over the past years, but with 66.2%, still many people depend on farming jobs. From all 71 crops listed by FAOSTAT (2020), 47 benefit or rely on animal pollination. In order to highlight the importance of bees as pollinators, we took a closer look at the agricultural land data. We calculated how much hectare production land benefits or relies on animal pollination and more specifically on pollination by bees (Fig. 4b). Data from 2018 revealed that 22.6% and 20.8% of hectare production land need or benefit from animal and specifically from bee pollination, respectively. From this animal pollinated crop areas in 2018, 92.3% are pollinated by bees, while the remaining 7.7% need other pollinators (e.g. bats, birds, beetles). Animal pollinated crop areas remain steady over the years 1993–2017 (Fig. 4b). It is expected that the demand for pollination increases with the hectare of farming land as it was described for Egypt (Al Naggar et al. 2018), but this was not the case for Ethiopia. Based on FAOSTAT data (2020), we observed that the production rates and hectare crop production area of non-pollinated crops such as maize, sorghum, wheat, sugar cane or barley increased more rapidly than those of pollination beneficiaries over the years. This is in strong contrast to the global trend of increasing demands for agricultural pollination services due to propagation of crops depending on animal pollination (Aizen and Harder 2009).

Similar to Al Naggar et al. (2018), we calculated beehives per hectare farming land profiting from bee pollination to investigate if Ethiopia suffers or heads toward a potential pollination gap. Between 1960 and 1990, the pollination in Egypt was secured but with increasing farming land and with the loss of almost half of all managed beehives, the situation crashed in 1990 and ever since, the pollination gap has become more and more of a problem. This can not be observed for Ethiopia and is supporting the trend for Ethiopia in the global analysis of Lautenbach et al. (2012), though our analysis includes also more recent data. Even though the numbers of beehives per hectare crop production area were similar to Egypt, the data for Ethiopia was stable over the time and therefore the risk of a pollination gap is currently considered to be low. This assumption is even reinforced, when it is taken into account, that in addition to 6 million hived bee populations, also 4 million feral bee colonies provide pollination services to crops and other plants.

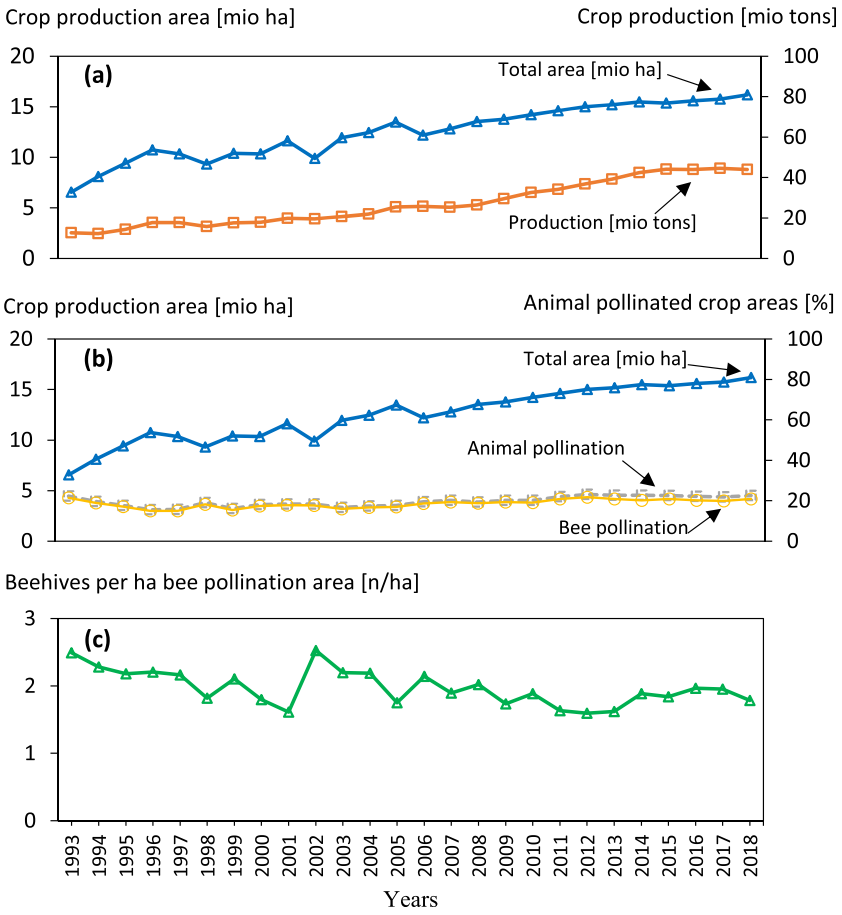


**Fig. 4** **a** Total crop production area [mio ha] and crop production [mio tons], **b** crop production area [mio ha] and animal-pollinated crop areas (benefitting at least moderately from animal pollination) [%] and **c** potential bee pollination gap for Ethiopia are shown. The latter was calculated similarly to Al Naggar et al. (2018) by relating the crop production area benefiting from bee pollination (honey bees and wild bees) in relation to the number of beehives (Fig. 2). Data source FAO (www.fao.org/faostat).

## 7 Conclusion and perspectives

Beekeeping in Ethiopia has a long tradition and the population values the opportunities honey bees provide. More than six million bee hives, maintained by more than one million beekeepers, produced 50,000 tons of honey and 5000 tons of beeswax in 2018, accounting Ethiopia to the top producers in the world. Still, 96% of hives are traditional systems with no or poor management. Local (Alebachew and Eshetie 2019), as well as international, programs (Wakjira et al. 2021) have committed themselves to provide help in the transition from traditional to transitional and modern beekeeping. In the SAMS project presented in Wakjira et al. (2021), attention was given to female/young beekeepers, honey value chain and new technologies for beekeeping in marginalized countries. Another result of this project was an online wiki including scientific and other references on bees and beekeeping in Ethiopia. Local programs such as Yesh (Young Entrepreneurs in Silk and Honey) and Moyesh (MOre Young Entrepreneurs in Silk and Honey) also support young Ethiopians and females who want to become beekeepers. The main problems in the Ethiopian beekeeping sector are limited availability of bee forage including water during droughts, swarming and absconding behaviour of bees, pests and predators, increasing use of pesticides on farming land, poor quality or no beekeeping equipment at all, lack of beekeeping know how and lack of storage and marketing facilities. Further, people face difficulties to transport their products from rural to urban areas due to a lack of infrastructure (Fikru et al. 2015; Gebremeskel et al. 2015; Gemechis 2016; Yirga and Teferi 2010; Yirga et al. 2012). Additionally, we identified several knowledge gaps, mostly on prevalence of diseases, bee taxonomy, assessment of key numbers, regional floral calendars, hive management actions and good beekeeping practice, migratory beekeeping and pollination business. There is clearly an increasing need and scope for studying the local honey bees and understanding the local beekeeping sector to close these gaps. Further, we found that modern and transitional hives do have advantages in honey productivity and hive management compared to traditional systems. Though, especially modern hive systems are accompanied by comparably high starting costs and a certain need of qualification and effort. For those beekeepers who do not want to invest too much in the beginning, transitional hive systems may be the right choice. The set-up is cost-effective and the level of required beekeeping skills is

lower. We therefore recommend new beekeepers to carefully evaluate their personal needs, the local areas and the availability of materials before choosing either a transitional, or a modern beehive system.

CSA Ethiopia conducts an annual agricultural survey among private peasant holdings. Even though the data source is from governmental origin, the numbers are based on a relatively small pool of survey participants and similar to FAO data provides estimations on livestock and livestock products. Thus, information varies based on the used data source (Fig. 2). Similar to other studies, we used publicly available FAO datasets for calculations related to pollination (Al Naggar et al. 2018; Moritz and Erler 2016). As also discussed by these authors, agricultural datasets often suffer from several issues, like that we do not exactly know which survey methods were used to collect the statistical data. Typically, the statistics are collected either by the local agricultural authorities or by FAO inspectors, but the survey methods strongly depend on the organization of the local authorities, the Ministry of Agriculture and reporting procedure. Secondly, values do not always exist for all crop types or time lines are incomplete, which is often bridged by providing estimations on those numbers. Last but not least, it cannot be ruled out completely, that the apparent crop production area is larger than the actual area, as Ethiopia may have several growing seasons and mixed cultivations. Nevertheless, and especially for developing countries, FAO data is often the only accessible or the most reliable data available and therefore was used for this review and is also referred to in many other publications.

In 2018, 3.7 million hectares of agricultural land needed, or benefited from bee pollination services, which were provided by a total of 10 million honey bee colonies. From those, four million are considered to be feral *A. mellifera* populations. This number is a rough estimation, and we do not know how it was assessed, but nevertheless, Ethiopia is a huge reservoir for honey bees and they only can be protected if the vegetation and forests as well as the agricultural lands will be protected by the citizens. Based on FAO data, we appreciated a relatively good supply of pollination services on the national level, even though divergences in regional settings were not assessed.

By progressively modernizing the Ethiopian apicultural sector through introduction of quality organs for honey and other bee products, switching to transitional and modern beehive systems, improvement of cooperation between players along the honey value chain, elaborating pollination economics, introduction of teaching institutions for beekeeping, strengthening the network of beekeepers and stakeholders, active protection of reservoirs for feral *A. mellifera* and other bee species and by research in those fields, Ethiopia has a great opportunity to tap its potential to become a top apicultural player in the future.

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**Authors' contributions** K.G. and R.B study design, K.G. wrote original draft, K.W. and R.B. reviewed and edited the draft, S.F. provided pictures, K.G. analysed the data. All authors read and approved the manuscript.

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**Data availability** The data used for the calculations in this review were obtained from the publicly available database of the Food and Agriculture Organization of the United Nations (FAO) http://faostat.fao.org as well as from the publicly available annual reports of CSA (Central Statistics Agency) Ethiopia.

**Code availability** Not applicable.

## Declarations

**Ethics approval** As the manuscript is a review article, an ethics approval is not applicable.

**Consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Conflict of interest** The authors declare no competing interests.



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