Journal of Innovative Agriculture
Review Article

Multifactorial constraints on honey production and innovative management in Indian apiculture

M. Mallikarjuna Rao[1*], Archunan Vinithra[2], Dharmalingam Kamaraj[3], Anbalagan Selva Amala[4], Govindaraj Kamalam Dinesh[5,6], Punabati Heisnam[7], Gopiraj Aruna[8], Bhargab Kalita[9], Osi Siram[10], Archana Anokhe[11], Brahmam Pasumarthi[12]

[1]Associate Professor, Department of Humanities & Sciences, PACE Institute of Technology & Sciences, Andhra Pradesh – 523272, India (mallikarjuna2009rao@gmail.com)
[2]Assistant Professor (Agricultural Entomology), Department of Entomology, Dhanalakshmi Srinivasan Agriculture College, Perambalur – 621 212, India (vinithra127@gmail.com)
[3]Department of Entomology, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai – 603 201, India (kamsentomology@gmail.com)
[4]Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore – 641 003, India (selvaamala.a@gmail.com)
[5]Department of Biochemistry,Physiology, Microbiology and Environmental Science, College of Agriculture, Central Agricultural University, Iroisemba, Imphal, Manipur – 795004, India (gkdineshiari@gmail.com; https://orcid.org/0000-0002-6605-9561)
[6]INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Negeri Sembilan, Malaysia
[7]Department of Agronomy, College of Agriculture, Central Agricultural University, Iroisemba, Imphal, Manipur – 795004, India (anuheisnam@gmail.com)
[8]Department of Plant Pathology, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai – 603 201, India (aruna.agri004@gmail.com)
[9]Department of Agronomy, College of Agriculture, Iroisemba, Central Agricultural University, Imphal, Manipur - 795 004, India (bhargab.kalitaagri@gmail.com)
[10]Department of Agronomy, College of Agriculture, Central Agricultural University, Iroisemba, Imphal, Manipur – 795004, India (osisiram1102@gmail.com)
[11]ICAR-Directorate of Weed Research Institute, Jabalpur – 482004, India (anokhearchana12@gmail.com)
[12]Associate Professor, Department of Humanities & Sciences, PACE Institute of Technology & Sciences, Andhra Pradesh – 523272, India (brahmampp147@gmail.com)

[*]Correspondence
M. Mallikarjuna Rao
mallikarjuna2009rao@gmail.com

Volume: 12, Issue: 3, Pages: 1-13
DOI: https://doi.org/10.37446/jinagri/ra/12.3.2025.1-13
Received: 9 June 2025 / Accepted: 29 August 2025 / Published: 30 September 2025

Honey bees (*Apis* sp.), popularly known as "golden insects", are economically important insects that fabricate honey. In addition to honey, they produce several high-value byproducts such as beeswax, royal jelly, bee venom, propolis, brood (larvae), and queen bees, all of which constitute marketable commodities within the apicultural sector. Honey is extensively used in the cosmeceutical and pharmaceutical industries. Along with this, the pollination carried out by the honey bees remains an essential condition to maintain agricultural productivity and biodiversity. Beekeeping in India is strongly supported by the secondary agricultural sector, which is deeply involved in the farmers' economics. The process of honey production is complex and multifactorial in nature, and several determinants limit it. The determinants encompass a range of factors that include biotic stresses such as bacterial, viral, amoebic, and acarine diseases; abiotic stresses, such as temperature fluctuation and moisture imbalance; and anthropogenic factors like pesticide and fungicide contamination. This review of the study focused on the constraints associated with beekeeping, honey production, and the quality of honey in managed apiculture site colonies. Furthermore, it discussed current strategies aimed at integrating medicinal properties into honey production through advanced management practices.

Keywords: *bee products, beekeeping, apiculture, medicinal floral resources, toxic chemicals, pesticides*

Introduction

The production of honey through apiculture is a challenging process. Scientific knowledge is required to achieve significant goals. There are four species of honey bees in India that are used to produce honey. Out of these, the Apis mellifera is the species most closely associated with beekeeping. Some of the diseases that are specified include infections caused by bacteria, viruses, amoebae, mites, tracheal, American foulbrood, and Sac infection that can lower the honey yield (Dey & Pal, 2020). Apiculture is an ideal choice for unemployed rural youth in Ethiopia. They shared reasons for high demand and cost of honey, difficulties of maintaining bee colonies in the field, and the challenges of producing bee products and managing colonies (Chanie et al., 2019). In Africa, a study was conducted to understand the factors that direct high-quality honey production. This study adopted a simple random sampling technique. Ultimately, it was determined that common pests, including rodents, mites, and beetles, negatively impact the quality of honey (Bett, 2017). In Tanzania, a study was conducted to determine the status of beekeeping. It estimated the factors, including climate change and anthropogenic factors, contributing to a decline in honey production. Figure 1 depicts the comprehensive overview of apiculture and honey production. Honey production was diminished due to rainfall and bushfires. However, these causes were minimal when compared to the impact of urbanization and farming. Still, livestock and grazing have been the main factors that have caused a severe drop in honey production (Nyunza, 2018). The Doppler radar approach was used to measure the health of the bee colony, their activity during the food search, and to assess the population of bees (Cunha et al., 2020). The ambitus process helped a group of farmers switch to organic honey farming, utilizing technology to increase honey production. It not only supports the change of the mode of production from the traditional to organic honey farming but also makes the transition easier (Oliveira et al., 2020).Some permissible limits were set by the council of the European Union and FAO/WHO for honey, the codex directive about sucrose in Ethiopia due to acidity in Sudan, enzyme content in Uganda, ash content, and acidic conditions of African countries, frequently training was given to the beekeepers to maintain honey quality, production, preservation and trading(Mesele, 2021).The United States study showed that beekeepers were vulnerable due to the loss of floral resources. To maintain their bee colonies, they needed to move from one region to another based on the availability of pollen and nectar. However, the presence of private land had a negative impact on the health of honey bees and decreased honey production (Durant, 2019).

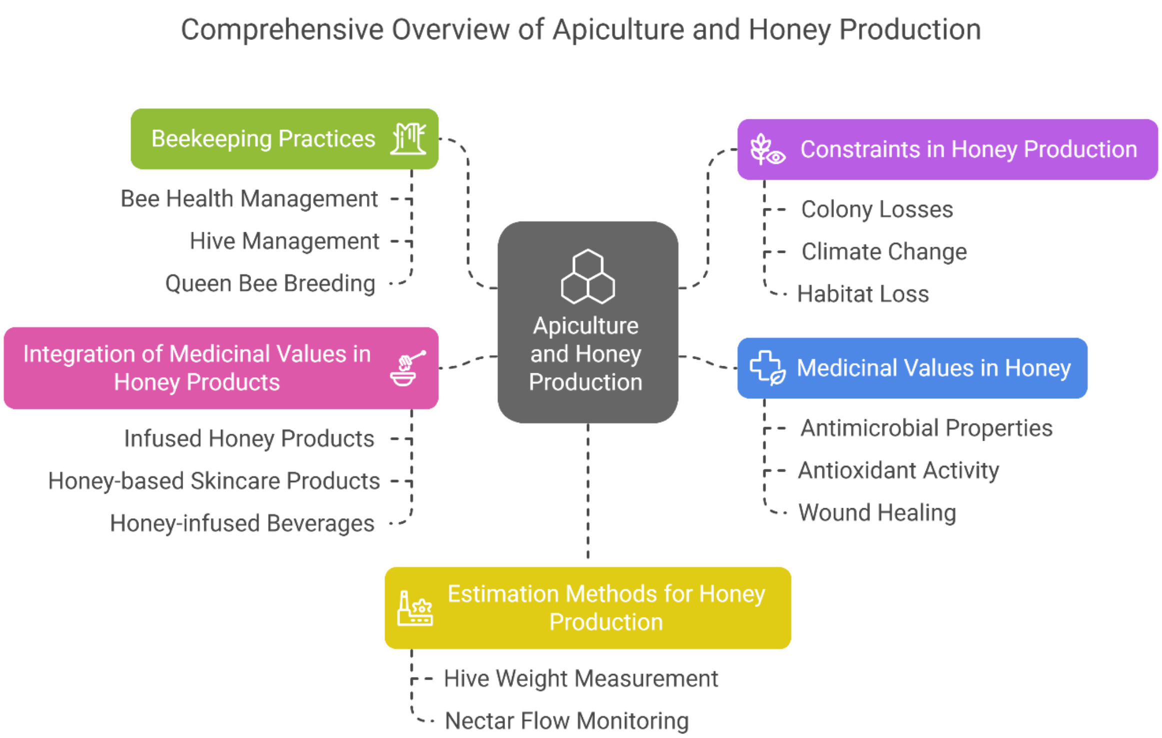

Figure 1. Comprehensive overview of apiculture and honey production

Landscape management plays a key role in apiculture. Infestation of mites causes severe damage to honey bee cultivation. It resulted in low-quality honey production and infections in the colonies (Dolezal et al., 2016). In Central and Eastern Java Island, kapok honey is produced by *Apis mellifera* bees. To determine the quality of honey, nine samples were collected, analyzed, and recorded. The honey samples were acidic, with hydroxymethyl furfural and lower sugar, sucrose concentrations, and all of the samples reached SNI 8664-2018 standards, but water content levels of the honey were more than the (22%) SNI limit (Adalina et al., 2019). In Nepal, the *Apis laboriosa* species has become reduced due to the clearing of forests and over-exploitation of cliff-nesting sites (Thapa et al., 2018). In Southern Ethiopia, honey was collected from different regions. Three seasonal honeys were collected and analyzed for quality. Physico-chemical properties, including moisture, conductivity, acidity, HMF, reducing sugars, and sucrose content, were found to exhibit significant differences in the collected samples. The results did not meet international standards for good quality honey (Engidaw et al., 2020). In Uganda, beekeeping is a significant industry for livelihood and income. Most beekeepers' complaints about practical beekeeping are associated with the high cost of beekeeping equipment, pathogenic infections, pests and predators, insufficient skills and awareness, inadequate extension services, lack of proper market information, and elevated transportation costs (Ayo, 2017).

Fourteen different honey spirits were collected from the market and analyzed for their physicochemical parameters. The results indicated notable variations in these parameters, with most samples exhibiting an alcohol content ranging from 37.4% to 53.0% and a low concentration of methanol (Anjos et al., 2017). Physical and chemical properties of the honeycomb were analyzed. The study compared a newly made honeycomb that has around 90% paraffin (PF-H) with a matured honeycomb beeswax (H) (Svečnjak et al., 2019). Another experiment was conducted to prepare muesli bars using a scientific method, incorporating natural honey to maintain the bar's structure. Additionally, a binder was created for a white sugar-free food without fats or additives (Laricheva & Mikhailova, 2020). Furthermore, antibiotics, pesticides, and heavy metal residues were detected in the honey samples, and their persistence was evaluated using precise and reliable analytical techniques (Barrasso et al., 2018).Various integrated methods have been developed to enhance the originality of Romanian honey, including spectrometric, spectroscopic, and chromatographic methods combined with chemometric data analysis (Geana & Ciucure, 2020).In Nepal, agricultural and forestry institutions have organized training programs on beekeeping for selected farmer groups. Proper beekeeping, monitoring, and management will generate potential income for the entrepreneurs (Shrestha, 2018).

Honey beekeeping

In West Bengal, a study was conducted to evaluate bee awareness among the local population regarding their perception of native bees. The majority of respondents complained about the improper use of pesticides as a significant factor contributing to the mortality of honeybees (Bhattacharyya et al., 2017).The Intensive application of neonicotinoid pesticides has been documented to exert adverse sublethal effects on honey bee colonies, resulting in foraging disorientation, brood damage, abnormal larval development, loss of memory, and impaired learning capacity (Magesh et al., 2017).The research also revealed that disrupted plant-insect smell signals, along with pollination aspects, communication changes in the olfactory system of insects and plants under an urbanized environment, and adverse agricultural practices have been observed. Pollination signals were interrupted by volatile organic compounds (VOCs) and reactive oxygen species, which caused mismatches in plant-pollinator interactions (Jürgens et al., 2017). Fire altered the plant-insect interactions by influencing the recognition of nesting sites and the exploitation of floral resources (Brown et al., 2017).

Studies on bumblebee colonies require more attention to the maintenance of both wild and managed pollinators, as well as the characterization of their endemism (Pirk et al., 2017). In Chandigarh, a study was conducted to map 20 medicinal nectar plant species, which were recorded in 11 trees, three shrubs, and six herbs across 13 familiesthat serve as potential forage for honey bees (Kumar et al., 2015).The Northeastern region of India presented an overview of pollination aspects in the selected area, elaborating on the importance of pollination in enhancing food security and daily life goods by increasing horticultural and vegetable production (Sharmah et al., 2015).Socioeconomic studies have further demonstrated the significance of apiculture. In 2016-17 in Haryana, the participants of a honey beekeeping entrepreneurship program were 96% male, 72% youth, 47% matriculated, and 51% farmers. It is noteworthy that 71% of the attendees were without land, and 73% had annual incomes lower than ₹1 lakh. On the bright side, the unemployed youth, marginal farmers, and landless labourers were full of enthusiasm to embrace beekeeping as their source of income (Singh et al., 2018).

One of the primary necessities for honey flow is flower availability. A study on plant species for bee forage in Nagpur identified a total of 63 species, comprising 41 wild species and 22 agro-horticultural plants. In the wild flora, nectar-yielding plants were 17, pollen-yielding plants were 4, and both nectar and pollen-yielding plants were 20. Agro-horticultural flora consisted of six nectar-only, five pollen-only, and 11 dual resource species (Waykar & Baviskar, 2015). On a worldwide scale, trade globalization and technological changes support new appearances and faster distribution of honey bee parasites, threats to apiculture, which are more severe in Asia (Chantawannakul et al., 2018). Another high-value bee product, propolis, has become more and more commercially relevant because of its medicinal properties. Indian propolis is the subject of the first scientific research done in 2004; however, some of the bioactivities of Indian propolis are ambiguous with specific regions and seasons (Kasote, 2017).

The risks resulting from pesticide residues are among the significant concerns that have not gone away. Comparisons of orchard plants revealed that fungicides like pyrimethanil and boscalid occurred at significantly lower concentrations in garden samples than in cultivated orchards, hence suggesting that managed gardens can supply less-contaminated floral resources for pollinators (Šlachta et al., 2020). On the other hand, neonicotinoids, especially imidacloprid (IMD) and thiamethoxam (TMX), have been found in floral resources all the time, meaning that they are a chronic toxicological risk to honey bees (Kessler et al., 2015). On a global scale, humans collect approximately 1,300 different types of plants for food, drinks, textiles, and medicines. Of these, 75% rely on animal-mediated pollination, with insects, birds, and mammals collectively contributing to 35% of pollination services. Notably, 87% of leading global crops benefit from pollination. However, escalating chemical pollution has disrupted pollination–pollinator interactions in both wild and managed ecosystems, impairing ecosystem functioning through altered feeding and nesting behaviours, poisoning, and pollinator health deterioration (Das et al., 2018). Additional anthropogenic factors, such as urbanization and technological expansion, have compounded risks to pollinator diversity. The proliferation of artificial electromagnetic radiation from nighttime illumination and wireless communication systems has emerged as a significant ecological stressor (Vanbergen et al., 2019). Evidence suggests that such radiation impairs honey bee navigation and colony cohesion, hindering worker bees' ability to provision and rear the next generation (Huang & Giray, 2012). Multifactorial Constraints and Innovative Management in Indian Apiculture are listed in Table 1.

Table 1. Multifactorial constraints and innovative management in Indian apiculture

Constraint Type	Problems	Innovative Management	References
Declining Bee Populations and Colony Collapse Disorder (CCD)	Stress factors such as inadequate food and environmental changes have caused a decrease in colony numbers. These issues have been prevalent in the states of Punjab, Uttar Pradesh, and Maharashtra.	The breeding of bees through Selective breeding and queen rearing programs has been the primary cause of the bees' resilience to diseases, giving a rise of 10-15% in honey production in Uttar Pradesh.	Manoj et al., 2023
Pesticide and Agrochemical Exposure	The use of neonicotinoids and organophosphates (for example, chlorpyrifos, imidacloprid) debilitates the immune system of bees, particularly in areas where many pesticides are used. This is considered a significant problem in Kerala (8th in production constraints).	Apiaries are being protected through the use of integrated pest management (IPM) with a significantly reduced use of chemicals, alongside the adoption of organic farming buffers.	Thomas et al., 2022
Habitat Loss and Climate Change	The cause of this has been urbanization, deforestation, and altered flowering patterns due to shifting climates (e.g., 2-3 week delays in blooming). Additionally, heat, drought, and rain extremes were ranked 2nd in Kerala production constraints (average score 58.75%).	Bee strains that could endure the effects of climate change were developed through breeding. At the same time, social forestry programs were encouraged to plant diversified forage.	Manoj et al., 2023
Pests and Diseases	The infestations of the Varroa mites (60-70% of colonies), Nosema (25-40% prevalence), foulbrood diseases (up to 10% in some states), wax moths, and hive beetles ranked 4th in Kerala (average score 46.58%).	The frequent check-ups and the use of organic treatments have brought about positive results, as well as the IPM protocols for mite control.	Dharni et al., 2023
Honey Adulteration and Quality Issues	More than 30% of the samples were adulterated, which affected the trust in the market and the exports.	The combination of blockchain technology with the FSSAI-compliant processing and branding has facilitated the traceability of the products.	Ornelas Herrera et al., 2025
Lack of Skilled Labor and Training	Lack of trained workers was the biggest problem in Kerala production (average score 67.15%), and only 20-25% of people adopted modern practices.	The government has set up training programs and extension services, providing rural youth with entrepreneurial opportunities.	Thomas et al., 2022

Economic and Infrastructural Barriers	The low market prices (ranked 1st in Kerala marketing constraints, average score 64.43%), high equipment costs, financial issues (ranked 6th in production, 45.91%), and poor infrastructure were the main factors that discouraged beekeepers.	Equipment is being subsidized; storage facilities have been improved, and direct sales to consumers are being conducted in accordance with FSSAI standards.	Dharni et al. 2023
Technological Adoption Gaps	The use of modern tools was minimal,partly due to inadequate extension services.	The use of IoT and AI for hive monitoring (e.g., Nectar Hive system) has led to a 15-20% reduction in mortality in Uttarakhand and Himachal Pradesh. The demand is expected to grow by 10-15% annually.	Alleri et al., 2023

Pathogen's infections

Honey was considered a natural and healthy food worldwide. However, to manage foulbrood disease in honeybee colonies, beekeepers often apply extensive antibiotics, which can lead to honey contamination and pose potential health risks to humans.Bacterial bee infections were one of the reasons for the decrease in wild and managed bee populations at the honey hive; on the other hand, neglected pathogens also caused some notable effects (*Spiroplasmas, Serratia marcescens, Lysinibacillus sphaericus*), not only the prominent one (*Paenibacillus larvae*, *Melissococcus plutonius*) (Fünfhaus et al., 2018). An experimental study was conducted on varroa disorder (caused by *Varroa destructor*, a mite) in honey bee hives. For this study, they treated honey bee hives in four different ways: 1. Chemotherapy, 2. Integrated Varroa Treatment, and 3. Natural compound treatment, 4. The Control group, without any Varroa treatment, among all the chemotherapies, showed better results in terms of Varroa infection, and comb formation was observed. Good neglected changes were observed after the treatment (Bąk et al., 2018). *Apis melliferae* are exposed to insecticides, especially flavonoids and secondary alkaloids, which plants generate. Fungi, on the other hand, produce mycotoxins. Moreover, beekeepers commonly apply antimicrobials, which cause the honey bee hives to accumulate toxic contaminants (Johnson, 2015). Losing or decreasing bee counts in winter, delayed autumn, and early spring seasons were outlined by local beekeepers, who experimented with providing abscisic acid as a dietary substrate for honey bees. This approach yielded positive results in honey regulation and syrup administration.

Additionally, they assessed the robust parameters of honey bee colonies, population dynamics, and honey bee nosemosis in *Apis mellifera* (Szawarski et al., 2019). *A. mellifera* is predominantly infected by American foulbrood disease, caused by *Paenibacillus larvae*, and it causes total hive deformations during the virulent phase of the infection. To reduce the *P. larvae* infection, they used a lactobacilli-loaded hive supplement, an easy-to-implement and affordable method for beekeepers to minimize enzootic pathogenic diseases (Daisley et al., 2020). A study highlighted that the antiviral defense mechanism in honey bees (*Apis mellifera*, *Apis cerana*, and *Bombus* spp.), as well as in Diptera, which was the model for Drosophila melanogaster and mosquitoes, provided the main framework for understanding the antiviral defense mechanism (McMenamin et al., 2018). Under the Disc diffusion method, Mahendran & Kumarasamy (2015) examined the antimicrobial properties of different honey samples, using five different microbes (*Escherichia coli*, *Staphylococcus aureus*, *S. pyogenes*, *Proteus mirabilis*, and *Pseudomonas aeruginosa*) to test the antimicrobial activity. Surprisingly perceptible differences were noticed among all the microbes. *S. aureus* was the most effective, inhibiting the maximum number of microbial colonies against the honey samples.

In the Bangalore region, honey samples were collected and tested for antimicrobial activity in the presence of *E. coli*. A 100% honey concentration inhibited microbial growth by forming a 36mm diameter zone. In contrast, a 50% concentration inhibited growth in a 22.83mm diameter zone. Besides, they were recorded that unifloral honey had a higher inhibition zone than multi-floral honey (Shishira et al., 2020). Natural and commercial honey was collected and tested for microbial activity in India. Kombu honey, Malan honey, and commercial honey were sampled from Chetheri Malai, Harur, and Tamil Nadu; among these, Kombu honey exhibited the highest antimicrobial activity against *S. aureus* (Molham et al., 2021).

A survey on Indian honey bee infections and disease probabilities revealed that the Southern Kerala, Kollam region had the highest infection rate of 44.36%, followed by Thiruvananthapuram at 4.45%. Adult honey bees become aggressive, contrary to their natural temperament, which decreases the number of bees in the colony. *Bacillus pumilus* and *Achromobacter* sp. were reported to be pathogenic against *Apis cerana indica* colonies (Joseph & VS, 2020). In Greece, a study was conducted using economic modelling to investigate the effects of neonicotinoid pesticides, which recorded a decrease in the concentration of neonicotinoids in honey under ideal infection and environmental pathogenic conditions (Chambers et al., 2019).

Pesticides effects

One hundred fifty honey samples were collected and analysed for residues of oxytetracycline, erythromycin, and chloramphenicol by using the ELISA test, and the results were confirmed against European Commission standards. FSSAI suggested that the optimal limit for oxytetracyclineis is 15.3%. However, the chemical is present in uncertified brand honey at 21.4%, unbranded honey at 14.3%, and certified branded honey at 10.2%. According to the FSSAI, all positive erythromycin samples were uncertified (Kumar et al., 2020). Northeastern India was blessed with an abundance of flora that supports honey bee populations for honey production. Different honey samples were collected from the local market and tested for their physicochemical properties. The samples exhibited bioactivity and contained mineral concentrations, phenolic, and flavonoid compounds (Mahnot et al., 2019). In the Garhwal Himalayas, India, 30 honey samples were collected and tested for heavy metals (Pb, Mn, Fe, Cu, Zn, Ni, and Cd) by using the ICP-MS method. The concentrations of heavy metals were recorded as being below the permissible limit set by the Codex Alimentarius Commission, and the honey was deemed suitable for human consumption (Tiwari et al., 2016). Pesticide residues in honey have been reported to pose potential health risks in human consumption. LC-MS/MS and GC/MS techniques were improved to analyse 46 pesticide residues in honey samples. Carbofuran, penconazole, difenoconazole, and metalaxyl residues were identified in the range between 3 and 30 µg/kg (Abdallah et al., 2017). Consumption of honey has been linked to damage to the human reproductive system. Ninety-two honey samples were collected from 27 countries, and the estimated pesticide residues in daily life and their associated reproductive toxicity were analysed. All of them belong to class IA toxicity, 42 to class II, 35 to class III, and one to class IV toxicity. This showed that the consumption of honey poses health risks to humans, as recommended by the Hazard Index (El-Nahhal, 2020). Karise et al. (2017). About 33 honey samples were analysed using HPLC-MS/MS and GC-MS for the presence of glyphosate, aminopyralid, and clopyralid. Eight active pesticide residues were identified and associated with three pesticides. Sometimes, the MRL concentrations were exceeded. Research was conducted to determine the physicochemical, antioxidant properties, and microbial composition of honey produced from sandbar pumpkin crops.

The honeybees were fed sugar supplements. The analysis revealed that the honey produced met all the parameters and reached the required standards (Kamal et al., 2019). A study was conducted on honey production, and it is related to environmental factors, including the area's topography, temperature, vegetation, and the availability of bee species (Taleuzzaman et al., 2020). Topographical and temporal changes influenced the energetics of honey bees exposed to organochlorine pesticides, Polychlorinated biphenyls, chlorpyrifos, and PBDEs. It concluded that land utilization and seasonal variations directly affected the concentrations of agrochemicals recorded in beehive matrices (Villalba et al., 2020).Wang et al. (2019) analysed monofloral, polyfloral honey samples using REIMS (Rapid Evaporative Ionization Mass Spectrometry)integrated with an electric soldering station, and classified them with 99.66% accuracy. Among all the samples, Acacia honey has a high nutritional value. Rape honey is composed of fewer nutrients. In the Republic of Serbia,55 honey samples of 3 types of honey werecollected. All samples were found to be within EU regulations, except for moisture and Hydroxymethyl furfural (Sakač et al., 2019). In Russia, the Ryazan region soils, plant matter, honey bees, and honey were collected and analyzed for heavy metals. The analysis revealed heavy metal deposits in honey bee bodies, propolis, pollen grains, and bee bread, indicating an excess of heavy metals. Luckily, the honey was not contaminated with heavy metals (Murashova et al., 2020).

Developing sites

In Ethiopia, a study was conducted to identify the potential biodiversity hotspots for honeybee conservation and beekeeping. They have optimized the flora and floral blooming calendar to enhance honey production. The botanical origin of honey was estimated through honey pollen analysis, which identified 74 plants belonging to 41 families. Among the recognized plant families, Asteraceae and Acanthaceae account for a significant portion of the support for honey production across four different seasonal durations (Bareke & Addi, 2019). Ethiopian women played a significant role in honey beekeeping. Gender norms and other societal limitations, as well as Cooperative and non-cooperative membership, notably increased the trading costs. It reduced the production volume of honey (Serra & Davidson, 2021). In South Africa, De Beer et al. (2021) observed a significant difference in the quality of imported and local honey, as measured by hydroxymethyl furfural and ash content; the honey sourced from agricultural fields differs from that of all other forage types. Honey bees were cultivated as a supplemental source of income, and they improved the yield of crops, such as potatoes. Technologies like small plots of agricultural land and alternative crop management in fields were implemented (Voiku, 2019). Hydroxymethyl furfural (HMF)concentration in a honey sample was estimated using spectrophotometry analysis; however, another study estimated HMF by employing an image processing technique at different temperatures. It correlated ($y=18.54x-1.224$, $R^2 = 0.987$), showing a good relationship with the spectrophotometry analysis and image processing (Erbakan et al., 2021). Technology integration and other monitoring techniques can increase honey production. In Ethiopia, data were collected from 180 households on the technical efficiency of honey production, using the stochastic frontier method for observation. Environmental factors were recorded using the Tobit model, and the estimated results showed a mean technical efficiency of 51.05% among the farmers' samples. This indicates significant inefficiency in honey fabrication; however, there is room to improve it by implementing the recently integrated technologies (Bati & Gemechu, 2020). In the Mediterranean and Atlantic regions, 40 honey samples were collected and analysed for Melissopalynological and physicochemical characteristics. The samples exhibited common parameters, including high mineral and phenol concentrations, increased electrical conductivity, and good amber colour intensity (Rodríguez-Flores et al., 2019). In Saudi Arabia, Remote sensing and GIS tools (Seldom) were used to elevate the maximum apicultural sites and bee colonies, and each Talha tree generates 8.5kg/season; by utilizing the RS & GIS technical approaches, they were designed, managed, monitored the apiculture sites, and estimated honey harvest in 12 beekeeping sites ie.1,278 bee colonies (Awad et al., 2019). Three beehive types were classified based on honey yield and money-making in Ethiopia. Among the three beehives, the Mekonen hive had the highest production (Negash et al., 2020). Heating was reported to be crucial for honey purification and filtration, and it facilitates long-term preservation; however, no standard guidelines were available for determining the optimal heating temperature and period. Uncontrolled temperature decreased the quality of honey and caused changes in its biological and chemical parameters. Enzyme activity and HMF content are key detection parameters used to determine the quality of honey in the international market (Eshete & Eshete, 2019).

The social life cycle assessment of honey was estimated using the subcategory assessment method, and a network for social sustainability was framed in the Italian honey production sector (D'Eusanio et al., 2018). Good-quality commercial honey parameters were guided by the Council Directive 2001/110/EC of 20 December 2001 (Council, 2002). Honey is fabricated by honeybees, which collect nectar from various floral sources. The nectar is primarily composed of sugars, including sucrose and glucose, and water, which can vary depending on the floral type. Honey is derived from the nectar of the honey bee hive. However, its composition includes various minerals, aromatic compounds, vitamins, organic acids, polyphenols, carbohydrates, and water. Honey contains high energy content, which was reported to be suitable for fit enthusiasts and sports personalities, and the best part is that it can be consumed by all age groups (Baglio, 2018). The Internet of Things (IoT) was implemented in stingless bee hives to monitor colony losses, providing information on bee colony temperature, moisture, weight, and behaviour. Additionally, it recorded information on the well-being of the bees (Yusof et al., 2019).

In Malaysia, an experimental tool (*i-BeeHOME*) was designed to monitor the stingless bee colonies and their honey production. The major features of *i-BeeHOME* were to provide information on favourable locations for beehives, estimate the potential for high-quality honey production, and track geographical positions (Nik et al., 2020). In Ethiopia, survey-based research was conducted to identify the major problems faced by honey beekeepers, including droughts, poor services, limited access to advanced technology, and deforestation, as well as the implementation and practice of outdated methodologies for honey beekeeping (Reda et al., 2018). Catania & Vallone (2020) reported that a honey bee hive needs continuous monitoring to maintain honey production temperature, moisture, and humidity inside and outside of the beehive; to achieve this, a research design precision apiculture system (PAS)was developed; it can be inserted with additional sensors that provide information on other parameters like rain and sound. To estimate the quantity of honey production, a research team installed an internet-based weight monitor sensor in the honeycomb, which measured the honey weight without causing any damage to the bees or the colonies (Ruan et al., 2017). Researchers in Turkey developed data mining algorithms, including CART, CHAID, and MARS, which help identify the factors (socioeconomic and biological predictors) that influence honey production (Aksoy et al., 2018). In Guinea-Bissau, Africa, honey was classified based on its botanical origin, including traditional and modern honey, and analysed for its chemical composition. Unpredictably, the majority of the parameters reached international standards (Lopes et al., 2018). In Ethiopia, an assessment study on beekeeping was carried out. It evaluated the major problems, including a lack of guidance on profitable beekeeping, poor beekeeping skills, insufficient human resources, a deficiency of beekeeping equipment, pest and predator threats, pesticide risks, inadequate infrastructure, reduced bee diversity, and poor research and extension (Sahle et al., 2018).

Conclusion

One of the significant opportunities for the country and the global market is honey enriched with medicinal properties and its derivatives. The consumers' desire will increase if honey's health benefits are promoted, which means that a larger market for export trade will be available. With the help of product and production diversifications in beekeeping, the honey sector will be revitalized with new businesses and start-ups that require minimal capital investment. As a result, the living standards of the farming communities, which are heavily reliant on beekeeping, will be improved. Indeed, all these interventions convey the message of the potentialities of beekeeping in the promotion of rural livelihoods, the maintenance of biodiversity, and the advancement of trade.

Author contributions

M. Mallikarjuna Rao:Writing – Original Draft Preparation; Archunan Vinithra: Writing – Original Draft Preparation; Dharmalingam Kamaraj: Writing – Original Draft Preparation, Anbalagan Selva Amala: Writing – Original Draft Preparation; Govindaraj Kamalam Dinesh – Visualisation, Writing – Review & Editing; Punabati Heisnam: Writing – Review & Editing, Gopiraj Aruna - Writing – Review & Editing, Bhargab Kalita: Writing – Original Draft Preparation; Osi Siram: Writing – Original Draft Preparation; Archana Anokhe: Writing – Review & Editing.

Acknowledgment

The authors would like to acknowledge their affiliated institutions for providing research facilities and access to literature through ONOS. The authors gratefully acknowledge and thank Pixabay, Flaticon, and Napkin for providing valuable resources that supported this work.

Funding

No funding.

Conflict of interest

The authors declare no conflict of interest. The manuscript has not been submitted for publication in any other journal.

Ethics approval

Not applicable.

AI tool declaration

The authors did not use any AI and related tools to write this manuscript. For English language improvement, Grammarly software is used.

References

Abdallah, O.I., Hanafi, A., Ghani, S.B.A., Ghisoni, S. and Lucini, L. (2017). Pesticides contamination in Egyptian honey samples. *Journal of Consumer Protection and Food Safety*, *12*(4), 317-327.

Adalina, Y., Heryati, Y., & Yuniati, D. (2019). Quality of kapok honey in some areas of Apis mellifera honey cultivation in Central Java and East Java Province. In *IOP Conference Series: Earth and Environmental Science* (Vol. 394, No. 1, p. 012049). IOP Publishing.

Aksoy, A., Ertürk, Y. E., Erdogan, S., Eyduran, E., & Tariq, M. M. (2018). Estimation of honey production in beekeeping enterprises from eastern part of Turkey through some data mining algorithms. *Pakistan Journal of Zoology*, *50*(6).

Alleri, M., Amoroso, S., Catania, P., Verde, G. L., Orlando, S., Ragusa, E., ... & Vella, A. (2023). Recent developments on precision beekeeping: A systematic literature review. *Journal of Agriculture and Food Research*, *14*, 100726. https://doi.org/10.1016/j.jafr.2023.100726.

Anjos, O., Frazão, D., & Caldeira, I. (2017). Physicochemical and sensorial characterization of honey spirits. *Foods*, *6*(8), 58.

Awad, A. M., Owayss, A. A., Iqbal, J., Raweh, H. S., & Alqarni, A. S. (2019). GIS approach for determining the optimum spatiotemporal plan for beekeeping and honey production in hot-arid subtropical ecosystems. *Journal of Economic Entomology*, *112*(3), 1032-1042.

Ayo, O. G. (2017). Socio-economic analysis of beekeeping and effects of different technologies on honey yields in Lira and Adjumani districts, Uganda.

Baglio, E. (2018). The industry of honey. An introduction. In *Chemistry and Technology of Honey Production* (pp. 1-14). Cham: Springer International Publishing.

Bąk, B., Wilde, J., & Siuda, M. (2018). The condition of honey bee colonies (Apis mellifera) treated for Varroa destructor by different methods. *Journal of Apicultural Research*, *57*(5), 674-681.

Bareke, T., & Addi, A. (2019). Bee flora resources and honey production calendar of Gera Forest in Ethiopia. *Asian Journal of Forestry*, *3*(2).

Barrasso, R., Bonerba, E., Savarino, A. E., Ceci, E., Bozzo, G., & Tantillo, G. (2018). Simultaneous quantitative detection of six families of antibiotics in honey using a biochip multi-array technology. *Veterinary sciences*, *6*(1), 1.

Bati, M., & Gemechu, J. K. Z. A. H. (2020). Technical Efficiency in Honey Production: The Case of Illubabor and Buno Bedelle Zones, South Western Ethiopia. *International Journal of African and Asian Studies*, *67*, 2409-6938.

Bett, C. K. (2017). Factors influencing quality honey production. *International Journal of Academic Research in Business and Social Sciences*, *7*(11), 281-292.

Bhattacharyya, M., Acharya, S. K., & Chakraborty, S. K. (2017). Pollinators unknown: People's perception of native bees in an agrarian district of West Bengal, India, and its implication in conservation. *Tropical Conservation Science*, *10*, 1940082917725440.

Brown, J., York, A., Christie, F., & McCarthy, M. (2017). Effects of fire on pollinators and pollination. *Journal of Applied Ecology*, *54*(1), 313-322.

Catania, P., & Vallone, M. (2020). Application of a precision apiculture system to monitor honey daily production. *Sensors*, *20*(7), 2012.

Chambers, R. G., Chatzimichael, K., & Tzouvelekas, V. (2019). Sub-lethal concentrations of neonicotinoid insecticides at the field level affect negatively honey yield: Evidence from a 6-year survey of Greek apiaries. *PLoS One*, *14*(4), e0215363.

Chanie, D., Melese, G., & Ayalew, H. (2019). Honey bee products marketing practices: Challenges and opportunities in and around Maksegnit Town, Amhara Region, Ethiopia. *AJAAR*, *10*(3), 1-8.

Chantawannakul, P., Ramsey, S., Khongphinitbunjong, K., & Phokasem, P. (2018). Tropilaelaps mite: an emerging threat to European honey bee. *Current opinion in insect science*, *26*, 69-75.

Council, E. U. (2002). Council Directive 2001/110/EC of 20 December 2001 relating to honey. *Official Journal of the European Communities L*, *10*, 47-52.

Cunha, A. S., Rose, J., Prior, J., Aumann, H. M., Emanetoglu, N. W., & Drummond, F. A. (2020). A novel non-invasive radar to monitor honey bee colony health. *Computers and Electronics in Agriculture*, *170*, 105241.

Daisley, B. A., Pitek, A. P., Chmiel, J. A., Al, K. F., Chernyshova, A. M., Faragalla, K. M., ... & Reid, G. (2020). Novel probiotic approach to counter Paenibacillus larvae infection in honey bees. *The ISME journal*, *14*(2), 476-491.

Das, A., Sau, S., Pandit, M. K., & Saha, K. (2018). A review on: Importance of pollinators in fruit and vegetable production and their collateral jeopardy from agro-chemicals. *Journal of Entomology and Zoology Studies*, *6*(4), 1586-1591.

De Beer, T., Otto, M., Pretoruis, B., & Schönfeldt, H. C. (2021). Monitoring the quality of honey: South African case study. *Food Chemistry*, *343*, 128527.

D'Eusanio, M., Serreli, M., Zamagni, A., & Petti, L. (2018). Assessment of social dimension of a jar of honey: A methodological outline. *Journal of Cleaner Production*, *199*, 503-517.

Dey, S., & Pal, N. (2020). Honey Bee and their Disease Management. *Agriculture & food: E-Newsletter, 2*(8), 493-494.

Dharni, K., Rathore, R., & Singh, M. (2023). Production and marketing of honey: Prospects and constraints – A review. *Biological Forum – An International Journal, 15*(8a), 407–413.

Dolezal, A. G., Carrillo-Tripp, J., Miller, W. A., Bonning, B. C., & Toth, A. L. (2016). Intensively cultivated landscape and Varroa mite infestation are associated with reduced honey bee nutritional state. *PLoS one*, *11*(4), e0153531.

Durant, J. L. (2019). Where have all the flowers gone? Honey bee declines and exclusions from floral resources. *Journal of rural studies*, *65*, 161-171.

El-Nahhal, Y. (2020). Pesticide residues in honey and their potential reproductive toxicity. *Science of the Total Environment*, *741*, 139953.

Engidaw, D., Alemayehu, K., Mustofa, S., & Tilahun, A. (2020). Effect of season on the major physico-chemical parameters of honey product. *Food and Environment Safety Journal*, *19*(1).

Erbakan, T., Sabanci, S., Baltaci, A., & Dirim, S. N. (2021). Investigation of the availability of image processing as an alternative method to spectrophotometry for prediction of HMF content in honey for different temperatures. *Journal of Food Processing and Preservation*, *45*(8), e14461.

Eshete, Y., & Eshete, T. (2019). A review on the effect of processing temperature and time duration on commercial honey quality. *Madridge Journal of Food Technology*, *4*(1), 158-162.

Fünfhaus, A., Ebeling, J., & Genersch, E. (2018). Bacterial pathogens of bees. *Current opinion in insect science*, *26*, 89-96.

Geana, E. I., & Ciucure, C. T. (2020). Establishing authenticity of honey via comprehensive Romanian honey analysis. *Food chemistry*, *306*, 125595.

Huang, Z. Y., & Giray, T. (2012). Factors affecting pollinators and pollination. *Psyche: A Journal of Entomology*, *2012*(1), 302409. https://doi.org/10.1155/2012/302409.

Joseph, J. P., & VS, A. (2020). Survey and etiology of bacterial brood disease infecting Indian honey bees (Apis cerana indica F.) in Southern Kerala. *Journal of Apicultural Research*, *59*(4), 519-527.

Jürgens, A., & Bischoff, M. (2017). Changing odour landscapes: the effect of anthropogenic volatile pollutants on plant–pollinator olfactory communication. *Functional Ecology*, *31*(1), 56-64.

Kamal, M. M., Rashid, M. H. U., Mondal, S. C., El Taj, H. F., & Jung, C. (2019). Physicochemical and microbiological characteristics of honey obtained through sugar feeding of bees. *Journal of Food Science and Technology*, *56*(4), 2267-2277.

Karise, R., Raimets, R., Bartkevics, V., Pugajeva, I., Pihlik, P., Keres, I., ... & Mänd, M. (2017). Are pesticide residues in honey related to oilseed rape treatments?. *Chemosphere*, *188*, 389-396.

Kasote, D. M. (2017). Propolis: A neglected product of value in the Indian beekeeping sector. *Bee World*, *94*(3), 80-83.

Kessler, S. C., Tiedeken, E. J., Simcock, K. L., Derveau, S., Mitchell, J., Softley, S., ... & Wright, G. A. (2015). Bees prefer foods containing neonicotinoid pesticides. *Nature*, *521*(7550), 74-76.

Kumar, A., Gill, J. P. S., Bedi, J. S., & Chhuneja, P. K. (2020). Residues of antibiotics in raw honeys from different apiaries of Northern India and evaluation of human health risks. *Acta Alimentaria*, *49*(3), 314-320.

Kumar, D., Sharma, V., & Bharti, U. (2015). Mapping of medicinal flora as honey bee forage. *Journal of Entomology and Zoology studies*, *3*(6), 235-238.

Laricheva, K., & Mikhailova, O. (2020). Development of scientifically-based recipe and technology for the production of natural honey-based muesli bar. In *IOP Conference Series: Earth and Environmental Science* (Vol. 613, No. 1, p. 012067). IOP Publishing.

Lopes, M., Falcão, S. I., Dimou, M., Thrasyvoulou, A., & Vilas-Boas, M. (2018). Impact of traditional and modern beekeeping technologies on the quality of honey of Guinea-Bissau. *Journal of Apicultural Research*, *57*(3), 406-417.

Magesh, V., Zhu, Z., Tang, T., Chen, S., Li, L., Wang, L., ... & Wu, Y. (2017). Toxicity of neonicotinoids to honey bees and detoxification mechanism in honey bees. *IOSR J. Environ. Sci. Toxicol. Food Technol*, *11*, 102-110.

Mahendran, S., & Kumarasamy, D. (2015). Antimicrobial activity of some honey samples against pathogenic bacteria. *International Letters of Natural Sciences*, *7*.

Mahnot, N. K., Saikia, S., & Mahanta, C. L. (2019). Quality characterization and effect of sonication time on bioactive properties of honey from North East India. *Journal of Food Science and Technology*, *56*(2), 724-736.

Manoj, M. S., Sharma, P., & Paschapur, A. U. (2023). Current Scenario of Beekeeping and Honey Production in India. *HEXAPODA*, 43-55. https://doi.org/10.55446/hexa.2023.591.

McMenamin, A. J., Daughenbaugh, K. F., Parekh, F., Pizzorno, M. C., & Flenniken, M. L. (2018). Honey bee and bumble bee antiviral defense. *Viruses*, *10*(8), 395.

Mesele, T. L. (2021). Review on physico-chemical properties of honey in Eastern Africa. *Journal of Apicultural Research*, *60*(1), 33-45.

Molham, F., Khairalla, A. S., Azmy, A. F., El-Gebaly, E., El-Gendy, A. O., & AbdelGhani, S. (2021). Anti-proliferative and anti-biofilm potentials of bacteriocins produced by non-pathogenic Enterococcus sp. *Probiotics and Antimicrobial Proteins*, *13*(2), 571-585.

Murashova, E. A., Tunikov, G. M., Nefedova, S. A., Karelina, O. A., Byshova, N. G., & Serebryakova, O. V. (2020). Major factors determining accumulation of toxic elements by bees and honey products. *International Transaction Journal of Engineering, Management and Applied Sciences and Technologies*, *11*(3), 11A03N.

Negash, D., Debara, M., Bekel, B., & Aregaw, A. (2020). Comparative Evaluation of Mekonen Beehive Technology with Zander and KTB Beehive Types on Honey Yield and Cost Benefit Analysis Under Sidama Condition, Ethiopia. *Materials Research*, *8*(2), 29-33.

Nik, W. N. S. W., Mohamad, Z., Zakaria, A. H., & Azlan, A. A. (2020). i-BeeHOME: An intelligent stingless honey beehives monitoring tool based on TOPSIS method by implementing LoRaWan–A preliminary study. In *Computational Science and Technology: 6th ICCST 2019, Kota Kinabalu, Malaysia, 29-30 August 2019* (pp. 669-676). Singapore: Springer Singapore.

Nyunza, G. (2018). Anthropogenic and climatic factors affecting honey production: The case of selected villages in Manyoni District, Tanzania. *Journal of Agricultural Biotechnology and Sustainable Development*, *10*(3), 45-57.

Oliveira, E. R. D., Muniz, E. B., Soares, J. P. G., de Fátima Lomba Farias, M., Gandra, J. R., de Araújo Gabriel, A. M., ... & Pereira, T. L. (2020). Environmental impacts of the conversion to organic honey production in family units of small farmers in Brazil. *Organic Agriculture*, *10*(2), 187-197.

Ornelas Herrera, S. I., Baba, Y., Erraach, Y., Ouertani, E., Arfa, L., Çamoğlu, S. M., ... & Kallas, Z. (2025). Analysing blockchain adoption in beekeeping: application of theoretical models and their effectiveness. *Frontiers in Sustainable Food Systems*, *9*, 1566341. https://doi.org/10.3389/fsufs.2025.1566341.

Pirk, C. W., Crewe, R. M., & Moritz, R. F. (2017). Risks and benefits of the biological interface between managed and wild bee pollinators. *Functional Ecology*, *31*(1), 47-55.

Reda, G.K., Girmay, S. and Gebremichael, B. (2018). Beekeeping practice and honey production potential in Afar Regional State, Ethiopia. *Acta Universitatis Sapientiae, Agriculture and Environment*, *10*(1), 66-82.

Rodríguez-Flores, M. S., Escuredo, O., Seijo-Rodríguez, A., & Seijo, M. C. (2019). Characterization of the honey produced in heather communities (NW Spain). *Journal of Apicultural Research*, *58*(1), 84-91.

Ruan, Z. Y., Wang, C. H., Lin, H. J., Huang, C. P., Chen, Y. H., Yang, E. C., ... & Jiang, J. A. (2017). An internet of things-based weight monitoring system for honey. *International Journal of Agricultural and Biosystems Engineering*, *11*(6), 478-482.

Sahle, H., Enbiyale, G., Negash, A., & Neges, T. (2018). Assessment of honey production system, constraints and opportunities in Ethiopia. *Pharm Pharmacol Int J*, *6*(1), 42-47.

Sakač, M. B., Jovanov, P. T., Marić, A. Z., Pezo, L. L., Kevrešan, Ž. S., Novaković, A. R., & Nedeljković, N. M. (2019). Physicochemical properties and mineral content of honey samples from Vojvodina (Republic of Serbia). *Food chemistry*, *276*, 15-21.

Serra, R., & Davidson, K. A. (2021). Selling together: the benefits of cooperatives to women honey producers in Ethiopia. *Journal of Agricultural Economics*, *72*(1), 202-223.

Sharmah, D., Khound, A., Rahman, S., & Rajkumari, P. (2015). Significance of honey bee as a pollinator in improving horticultural crop productivity in NE Region, India: A review. *Asian Journal of Natural y Applied Science*, *4*(1), 62-69.

Shishira, D., Eshwarapp, G., Shwetha, B.V., & Kuberappa, G.C. (2020). Antimicrobial activity of honey against pathogenic bacteria (*Escherichia coli*). *Journal of Pharmacognosy and Phytochemistry*, *9*(2), 1815-1817.

Shrestha, A. (2018). Study of Production Economics and Production Problems of Honey in Bardiya District, Nepal. *Sarhad Journal of Agriculture*, *34*(2), 240-245.

Singh, B., Singh, S., & Batra, A. (2018). Socio-economic status of the people adopting beekeeping as an entrepreneurship. *International Journal Current Microbiology and Applied Science*, *7*(07), 143-149.

Šlachta, M., Erban, T., Votavová, A., Bešta, T., Skalský, M., Václavíková, M., ... & Cudlín, P. (2020). Domestic gardens mitigate risk of exposure of pollinators to pesticides—an urban-rural case study using a red mason bee species for biomonitoring. *Sustainability*, *12*(22), 9427.

Svečnjak, L., Jović, O., Prđun, S., Rogina, J., Marijanović, Z., Car, J., ... & Jerković, I. (2019). Influence of beeswax adulteration with paraffin on the composition and quality of honey determined by physico-chemical analyses, 1H NMR, FTIR-ATR and HS-SPME/GC–MS. *Food chemistry*, *291*, 187-198.

Szawarski, N., Saez, A., Domínguez, E., Dickson, R., De Matteis, Á., Eciolaza, C., ... & Negri, P. (2019). Effect of abscisic acid (ABA) combined with two different beekeeping nutritional strategies to confront overwintering: Studies on honey bees' population dynamics and nosemosis. *Insects*, *10*(10), 329.

Taleuzzaman, M., Kala, C., & Gilani, S. J. (2020). Validation, chemical composition, and stability of honey from Indian Himalayas. In *Therapeutic Applications of Honey and its Phytochemicals: Vol. 1* (pp. 81-100). Singapore: Springer Singapore.

Thapa, R., Aryal, S., & Jung, C. (2018). Beekeeping and honey hunting in Nepal: Current status and future perspectives. *Asian beekeeping in the 21st century*, 111-127.

Thomas, C. A., Ramchandra, D., Biswas, S., & Ansari, A. A. (2022). Constraints related to production and marketing of honey in Pathanamthitta district of Kerala. *The Pharma Innovation Journal, 11*(5S), 1383–1385.

Tiwari, P., Naithani, P., & Tiwari, J. K. (2016). determination of heavy metals in honey samples from sub-montane and montane zones of Garhwal Himalaya (India). *World J Pharm Pharmac Sci*, *5*(7), 812-19.

Vanbergen, A. J., Potts, S. G., Vian, A., Malkemper, E. P., Young, J., & Tscheulin, T. (2019). Risk to pollinators from anthropogenic electro-magnetic radiation (EMR): Evidence and knowledge gaps. *Science of the Total Environment*, *695*, 133833.

Villalba, A., Maggi, M., Ondarza, P. M., Szawarski, N., & Miglioranza, K. S. B. (2020). Influence of land use on chlorpyrifos and persistent organic pollutant levels in honey bees, bee bread and honey: Beehive exposure assessment. *Science of the Total Environment*, *713*, 136554.

Voiku, I. (2019). The technology of co-culturing of potatoes with honey plants and prospects of its technical support. In *ENVIRONMENT. TECHNOLOGIES. RESOURCES. Proceedings of the International Scientific and Practical Conference* (Vol. 1, pp. 339-343).

Wang, H., Cao, X., Han, T., Pei, H., Ren, H., & Stead, S. (2019). A novel methodology for real-time identification of the botanical origins and adulteration of honey by rapid evaporative ionization mass spectrometry. *Food Control*, *106*, 106753.

Waykar, B., & Baviskar, R. K. (2015). Diversity of bee foraging flora and floral calendar of Paithan taluka of Aurangabad district (Maharashtra), India. *Journal of Applied Horticulture*, *17*(2), 155-159.

Widawski, K., & Oleśniewicz, P. (2019). Thematic tourist trails: Sustainability assessment methodology. The case of land flowing with milk and honey. *Sustainability*, *11*(14), 3841.

Yohannes, W., Chandravanshi, B. S., & Moges, G. (2018). Assessment of trace metals and physicochemical parameters of commercially available honey in Ethiopia. *Chemistry International*, *4*(2), 91-101.

Yusof, Z. M., Billah, M. M., Kadir, K., Ali, A. M. M., & Ahmad, I. (2019, August). Improvement of honey production: A smart honey bee health monitoring system. In *2019 IEEE International Conference on Smart Instrumentation, Measurement and Application (ICSIMA)* (pp. 1-5). IEEE.