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MINISTRY OF AGRICULTURE

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Livestock Development Institute

National Honeybee Breeding Strategy (2026-2035)

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MESSAGE

Ethiopia is a nation of immense natural endowments, and among our greatest treasures is our apiculture sector. With over 10 million honeybee colonies, we proudly stand as the leading producer of honey in Africa and the third-largest producer of beeswax globally. Beekeeping is an environmentally friendly cornerstone of our rural economy, providing a lifeline for over two million households and offering a pathway to prosperity for our women and youth. However, as we look toward the future, we must confront a sobering reality: we are currently tapping into only 26% of our national honey production potential. While our well-managed modern hives can yield over 45 kg annually, our national average remains about half of it.. This gap is not due to a lack of resources, but rather a lack of structured, scientific intervention in honeybee breeding and management.

The National Honeybee Breeding Strategy (2026–2035) marks a transformative shift in our approach. For too long, our beekeeping subsector has relied on traditional methods that, while culturally significant, cannot meet the rising economic demands of a growing population and a competitive global market. This strategy provides the systematic framework necessary to modernize the sector through the generation, adaptation, and transfer of demand-driven technologies. Our vision for 2035 and beyond is clear: to see market-oriented beekeepers thriving through sustainable genetic improvement programs. This strategy introduces high-level scientific interventions, including: genetic improvement and conservation, digital transformation, climate resilience, and infrastructure development by building and strengthening nucleus breeding centers and mating stations across the country to ensure the supply of elite queen bees to our farmers.

Implementation is the true measure of any strategy. The Ministry of Agriculture provides the necessary policy support and oversight to see these goals realized. However, the government cannot act alone. The success of this 10-year roadmap requires a robust partnership between research institutions, our regional bureaus, higher learning institutions, development partners, and, most crucially, the private sector. We invite investors to recognize the “liquid gold” potential of Ethiopia’s honey and beeswax. By engaging in stock multiplication and service delivery, the private sector will play a pivotal role in creating a sustainable value chain that feeds both domestic agro-processors and international markets.

To our beekeepers, researchers, and extension experts: this strategy is your guide. It is designed to empower you with the tools and knowledge to turn our indigenous honeybee races into high-performing assets that secure food nutrition and alleviate poverty. Together, let us embark on this decade of progress, ensuring that the buzz of the Ethiopian honeybee remains a symbol of our nation's growth, resilience, and prosperity.

State Minister, Ministry of Agriculture

Federal Democratic Republic of Ethiopia

FOREWARD

Ethiopia is historically and culturally recognized as the "land of honey." As the leading honey producer in Africa and the tenth largest globally, our nation is blessed with diversity of honeybee species and over 10 million colonies. For more than two million Ethiopian households, beekeeping is not merely an agricultural activity; it is a vital lifeline, a source of sustainable income, and a cornerstone of rural resilience. However, a significant gap remains between our vast potential and our current reality. While we possess the largest bee population on the continent, we are currently tapping into only about 26% of our production capacity. The predominance of traditional management systems and the absence of a structured, scientific approach to genetic improvement have limited our productivity. To transform this sub-sector into a modern, competitive, and market-oriented engine of economic growth, we must transition from traditional practices to precision breeding and evidence-based management.

The National Honeybee Breeding Strategy (2026–2035) represents a decisive roadmap for this transformation. This decade-long strategy is designed to bridge the productivity gap by focusing on the genetic improvement of our indigenous honeybee ecotypes. By prioritizing economically important traits such as high honey yield, docility, and disease resistance while simultaneously conserving the unique biodiversity that makes Ethiopian honey world-renowned, we are securing both our economic future and our environmental heritage. This strategy is not an isolated effort. It is meticulously aligned with Ethiopia's broader national development goals, including the Climate Resilient Green Economy (CRGE) policy and the Livestock Master Plan. It recognizes that the challenges of the 21st century most notably climate change and habitat loss require "climate-smart" apiculture. By integrating advanced biotechnological tools, such as genomic selection and artificial insemination, with community-based participatory breeding, we ensure that the benefits of modern science reach the smallholder beekeepers, women, and youth who are the backbone of this industry.

The success of this strategy depends on the collective commitment of all stakeholders. It requires seamless coordination between the Ministry of Agriculture, research institutes, higher learning institutions, the private sector, and our development partners. Most im-

portantly, it requires the active participation of the beekeepers themselves. On behalf of LDI, I would like to express my gratitude to the experts, researchers, and stakeholders who contributed to the formulation of this comprehensive document. I call upon all actors in the apiculture value chain to embrace this strategy with dedication.

Together, we will ensure that Ethiopia's beekeeping sector becomes a global model of productivity and sustainability, providing a better life for our beekeepers and contributing significantly to our national prosperity.

Asrat Tera (PhD)
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By bridging the gap between potential and current yields, the National Honeybee Breeding Strategy will unlock Ethiopia's untapped apiculture potential. The expected outcomes include: enhanced productivity and job creation through private sector engagement; conservation of unique indigenous honeybee ecotypes and increased climate resilience; and higher incomes and food security for smallholder beekeepers and commercial operators alike. Through systematic monitoring and the broad dissemination of superior genetic material, this strategy will ensure long-term genetic gains, securing Ethiopia's position as a global leader in sustainable honey production.

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Acronyms/Abbreviations

AI	Artificial Insemination
ATI	Agricultural Transformation Institute
BLUP	Best Linear Unbiased Prediction
CRGE	Climate Resilient Green Economy
CSA	Central Statistics Agency
csd	complementary sex determination (gene)
DNA	Deoxyribonucleic Acid
EIAR	Ethiopian Institute of Agricultural Research
ESAP	Ethiopia Society of Animal Production
ETB	Ethiopian Birr
EUT	Economically Useful Traits
EVA	Ethiopian Veterinary Association
FDRE	Federal Democratic Republic of Ethiopia
G1	First Generation (of improved stock)
HLI	Higher Learning Institutions
HPLC	High-Performance Liquid Chromatography
ICT	Information and Communication Technology
kg	Kilogram
KPI	Key Performance Indicator
LDI	Livestock Development Institute
LMP	Livestock Master Plan
M&E	Monitoring and Evaluation
M	Million
MoA	Ministry of Agriculture
NARC	National Agricultural Research Council
Ne	Effective Population Size
NPV	Net Present Value
PCR	Polymerase Chain Reaction
PPP	Public-Private Partnership
REW	Relative Economic Weights
ROI	Return on Investment
SNP	Single Nucleotide Polymorphism
SQL	Structured Query Language (referring to database integration)
SWOT	Strengths, Weaknesses, Opportunities, and Threats
VSH	Varroa Sensitive Hygiene

EXECUTIVE SUMMARY

Ethiopia holds the distinction of being Africa's leader in honey production, boasting over 10 million honeybee colonies. Despite this vast biological wealth and the subsector's role in supporting two million rural households, the country currently realizes only 26% of its 500,000-ton annual production capacity. This significant productivity gap stems from a primary reliance on traditional management systems, the use of low-yielding genetic stock, and the absence of a systematic breeding framework. To address these challenges, the National Honeybee Breeding Strategy has been developed, aligning with national priorities such as the Climate Resilient Green Economy (CRGE) and the Livestock Master Plans (LMP).

The strategy establishes an organized, scientifically driven, and institutionalized framework for the genetic improvement, conservation, and sustainable utilization of Ethiopia's indigenous honeybee resources. Its Vision is to transform Ethiopia into a hub of market-oriented beekeeping by 2030 through sustainable genetic programs. The key objectives include: designing organized genetic improvement programs; deploying advanced tools, including genomic selection and climate-smart innovations; and strengthening institutional capacity and stakeholder collaboration.

The strategy follows a phased approach to transition from traditional practices to modern breeding. Short-term actions prioritize the characterization of honeybee ecotypes, the design of breeding programs, the establishment of nucleus centers, and the creation of stakeholder linkages. Medium-term efforts will focus on scaling up queen multiplication and intensifying conservation efforts. Central to this approach is the Open Breeding Scheme, which emphasizes participatory selection for economically vital traits such as high honey yield, docility, and disease resistance. These efforts will be supported by rigorous recording systems and the integration of modern genomic tools.

To ensure accountability, the Ministry of Agriculture (MoA) and the Livestock Development Institute (LDI), in collaboration with national research centers, will lead the coordination, implementation, and monitoring of the strategy. This integrated governance model is designed to consolidate previously fragmented efforts into a unified national program.

1. Introduction

1.1. Background

Ethiopia is recognized across Africa for its exceptional beekeeping potential, characterized by a rich diversity of honeybee species and the largest number of honeybee colonies on the continent. These factors position Ethiopia as a leading honey producer, ranking first in Africa and tenth globally. Additionally, the country stands as the third-largest producer of beeswax. The country's biodiversity and varied agro-climatic conditions significantly enhance its capacity for substantial honey and beeswax production. In addition to table honey, Ethiopia has opportunities for producing mono-floral honey, industrial honey, and organic and fair-trade varieties. Beekeeping is a traditional practice in Ethiopia, deeply embedded in the agricultural landscape. This environmentally friendly activity plays a crucial role in the economic and social development of the nation, providing sustainable income and self-employment for approximately two million beekeeping households. Furthermore, beekeeping is a vital strategy for poverty alleviation in many developing nations (Amulen et al., 2019).

Ethiopia owns the largest bee population in Africa, with over 10 million honeybee colonies. Of these, approximately 6,986,100 colonies are estimated to be hived, while the remainder exists in the wild (CSA, 2021). The Ethiopian honeybee population is exclusively composed of local races. Among the hived colonies, only 183,924 (or 2.63%) are managed in modern beehives, and 102,957 (or 1.47%) in transitional hives. This highlights a significant need for improvements in the country's beekeeping systems. The nation has an estimated honey production capacity of 500,000 metric tons, yet current output is limited to approximately 129,301 metric tons (CSA, 2021), representing only about 26% of its potential. The national average honey yield per frame hive is 20.88 kg per annum (CSA, 2022), while well-managed modern beekeeping systems can yield over 45 kg annually per hive. However, reaching these production levels requires comprehensive interventions aimed at improving both the production and productivity of honeybees by addressing various constraints within the value chain.

Therefore, this honeybee breeding strategy spans over short and medium time horizons will serve the national honeybee breeding program as a guideline for generation, adaptation and transfer of tailor-made and demand-driven technologies and innovation that can enhance production and productivity which ultimately leads to ensure food security; provide raw materials to domestic agro-processors and export market.

1.2. Rationale for Developing the Strategy

Beekeeping plays a crucial role in supporting the livelihoods of millions of farmers in Ethiopia. It is viewed as a potential economic driver for smallholder farmers, women, and unemployed youth. Despite its significance, the productivity of local honeybee colonies remains low due to insufficient interventions. This low productivity indicates a lack of effective breeding strategies and programs aimed at sustainable genetic improvement. Therefore, there is a pressing need for a comprehensive breeding strategy that facilitates selective breeding to enhance the genetic quality of local honeybees.

To tap into the unexploited potential of beekeeping, strategies must be developed that align with current development policies, population growth trends, and economic demands. Additionally, it is essential to integrate the national breeding strategy with national development plans, such as the Climate Resilient Green Economy (CRGE) policy and the research master plans established by the National Agricultural Research Council (NARC). This alignment is vital for transforming Ethiopian beekeeping into a competitive sector that can significantly improve livelihoods, ensure food security, supply raw materials to domestic agro-processors, substitute imports, and contribute to overall economic growth.

1.3. Vision

By 2035, to see improved livelihood and market-oriented beekeepers in Ethiopia through applying suitable and sustainable honeybee genetic improvement strategic programs.

1.4. Mission

To make efficient utilization of the country's honeybee resource base and beekeeping potential through sound genetic improvement, stock conservation and sustainable utilization in order to improve the livelihoods of beekeepers and increased the contribution of beekeeping to the national economy.

1.5. Goal

To enhance beekeeping production and productivity to ensure food nutrition security and poverty reduction in the country and ensure a better life for beekeepers in Ethiopia.

1.6. Objectives

General Objectives: the overall objective of the strategy is to guide the future honeybee

genetic improvement, conservation and sustainable utilization of beekeeping subsector through organized, rationalized, scientific and institutionalized that lead to sustainable economically viable breeding programs.

1.7. Specific Objectives

- To develop and implement well-organized and consistent honeybee genetic improvement programs across different production systems.
- To apply different breeding tools including genomic selection, artificial insemination and developing elite queens and conserve indigenous honeybee genetic resources.
- To develop climate smart technologies and innovations for honeybee management that addresses the impacts of climate change and variability.
- To enhance the capacity for the research system, development institutions, private sector and small holders in different production systems.

1.8. Scope of the Breeding Strategy

Ethiopia has significant potential for honey production due to the country's diverse climatic conditions and large honey bee population. The country is home to over 10 million bee colonies, making it one of the largest bee populations in Africa. Enhancing breeding strategies can improve honey yield and quality, as current practices predominantly rely on traditional methods that result in lower productivity. By adopting modern breeding techniques and focusing on local bee populations, Ethiopia can boost honey production, improve the livelihoods of rural communities, and capitalize on the growing global demand for honey. This honeybee breeding strategy has been developed within a framework of addressing both development and research aspects at national level in order to serve as guideline for genetic improvement of economical important honey bee traits until 2030. This document will serve for all concerned stakeholders as reference guideline for designing breeding programs, evaluation and selection, technique of breeding, strengthening of service delivery, capacity building and the application of conventional and advanced technologies that can support indigenous honeybee ecotype population improvement, conservation and multiplication.

1.9. Guiding Principles

The national honeybee breeding strategic intervention and the specification of the modalities of intervention is guided by a set of basic governing principles. These are:

- The national honeybee genetic improvement shall be an integral part of the national research for development efforts and guided by basic principles put forward by the national livestock master plan.
- All the activities shall be founded on the policies and priorities set in road map for national genetic improvement strategy for honey bee in the Livestock Master Plan embracing the notions of cost-effectiveness, technical efficiency and responsiveness to stakeholders in both the public and private sector
- In the process of project formulation and implementation, real participation and engagement of the community shall be ensured. The national honeybee genetic improvement activities shall follow participatory approach and ensure sufficient degree of client orientation.
- Through its impact path way, the national honeybee genetic improvement shall ensure its research for development outputs will contribute to macro level goals of economic/ social transformation, sustenance of environment and livelihood improvement.
- During project formulation and implementation the required ethical, social and environmental impacts shall be ensured.
- In the national honeybee genetic improvement engagement special emphasis shall be given to capacity building, institutionalization of integrated approach, institutional pluralism and effective engagement of partners and stakeholders on the basis of comparative advantage.
- Due attention shall also be given to inclusiveness in terms of diversity and equal opportunity for all encompassing gender-sensitive approaches in its research for development engagement.
- In all of its deliberations, the national honey bee genetic improvement shall ensure

commitment to excellence, knowledge sharing and access to information.

- In the national honeybee genetic improvement engagements, monitoring mechanisms and evaluation criteria from inception of its projects and activities shall be ensured.
- The national honeybee genetic improvement activities shall be free from all forms of malpractices and shall ensure transparency, accountability and devotion to ethical standards of all concerned actors at all levels.

2. Situation Analysis

2.1. Beekeeping Systems and Development Goal

Ethiopia's beekeeping system is diverse and can be categorized into three main types: traditional, transitional (intermediate), and frame hive (modern) systems. Each system reflects the local practices and resources available to beekeepers across the country. Traditional beekeeping system is predominant beekeeping system in Ethiopia covering about 90% of the country. This system is further classified in to the backyard and forest traditional beekeeping systems.

Backyard Traditional Beekeeping: This method is primarily found in the central and northern regions of Ethiopia. Beekeepers typically use locally constructed cylindrical hives made from materials like wood and clay, which are fixed-comb hives that do not allow for easy inspection or management of the bees (Shanku and Ijara, 2024, Teferi, 2018).

Forest Traditional Beekeeping: predominant in the southern and southwestern areas, this method involves placing hives in forested areas, where bees can forage naturally. However, it is considered less safe compared to backyard systems due to potential threats from wildlife and environmental factors (Shanku and Ijara, 2024, Teferi, 2018).

The transitional (intermediate) beekeeping: represents a significant step between traditional and modern beekeeping systems, aimed at enhancing honey production while integrating sustainable practices. This method employs locally made beehives, such as the Kenyan top-bar hive, which are easier to manage than traditional hives and more accessible than modern hives.

The frame hives (modern hive) beekeeping system: is found in backyard and conserved areas where the beekeeping management knowledge and skill is very high. The system comprises mainly small and medium size commercial beekeeping farms. The primary objective of the producers in this production system is to produce and sale honey and other bee product as a means of income generation. Most of the commercial and semi-commercial beekeeping farms possess frame hives (modern hives) and produce about 2% of the total honey production of the country.

2.2. Global Situation Analysis in Honeybee Breeding

Honeybee breeding is a multifaceted discipline that merges genetics, environmental influences, and management practices to boost the productivity and resilience of bee colonies. This analysis examines the current landscape of honeybee breeding, emphasizing genetic techniques, breeding values, and the challenges encountered in this field.

The situation analysis of honeybee breeding highlights a vibrant sector that integrates cutting-edge genetic methods with effective management strategies. Despite ongoing challenges such as polyandry and environmental variability, continuous research and advancements in genetic techniques offer promising opportunities for enhancing the efficiency and sustainability of honeybee populations globally.

2.2.1. Genetic Methods in Honeybee Breeding

The breeding of honeybees, particularly the species Apis mellifera, involves several genetic techniques aimed at improving economically useful traits (EUT) such as honey productivity, disease resistance, and behavioral characteristics. Key methodologies include:

1. Subspecies Identification: Accurate identification of honeybee subspecies is crucial for effective breeding. Genetic analysis, including polymorphism studies of nuclear and mitochondrial DNA, helps confirm subspecies classifications (Kashinova et al., 2023).

2. Allelic Diversity Assessment: The assessment of the complementary sex determination (csd) gene is vital for understanding genetic diversity within colonies. This gene influences inbreeding outcomes and is essential for selecting appropriate mating pairs (Kashinova et al., 2023).

3. Health Diagnostics: DNA diagnostics are employed to evaluate the health status of colonies, ensuring that only healthy bees are used in breeding programs (Kashinova et al., 2023).

4. Breeding Value Estimation: The breeding value reflects the genetic potential of a queen or worker bee based on traits such as honey yield and hygienic behavior. This estimation can be improved by accounting for environmental effects and genetic relationships among colonies (Uzunov et al., 2023).

2.2.2. Breeding Strategies

Effective honeybee breeding strategies involve multiple stages:

Initial Selection: Selecting colonies from a genetically uniform population to minimize hybridization risks.

Evaluation of EUT: Continuous assessment of colonies based on their performance in terms of productivity and health.

Genetic Pairing: Forming mating pairs based on csd allele diversity to enhance genetic robustness in offspring (Kashinova et al., 2023).

2.2.3. Challenges in Honeybee Breeding

Despite the potential benefits of honeybee breeding, several challenges exist:

Resource Requirements: Successful breeding programs often require access to hundreds or thousands of colonies for effective selection, which can be a barrier for smaller operations.

Polyandry: Honeybee queens mate with multiple drones, complicating genetic predictions and selection processes.

Environmental Influences: Variability in environmental conditions affects colony performance, necessitating adjustments in breeding strategies to isolate genetic factors from environmental impacts (Uzunov et al., 2023; Palacio et al., 2024).

Inbreeding Risks: The closed nature of some breeding programs can lead to increased inbreeding depression, highlighting the need for careful management of genetic diversity

within populations (Kashinova et al., 2023). Many commercial breeds are inbred, leading to reduced genetic diversity which can limit resilience against diseases (Pries et al., 2020).

2.3. Economic Implications

The economic aspects of honeybee breeding are significant. Selective breeding can lead to increased productivity and reduced colony losses, thereby enhancing profitability for beekeepers. Effective breeding programs not only improve bee health but also contribute to sustainable beekeeping practices that benefit both producers and ecosystems (Dimitrov et al., 2024).

3. SWOT Analysis

The current status and progress of honeybee genetic improvement present both strengths and weaknesses that can inform future advancements in the field. These strengths and weaknesses are internalities to the current state of the apiculture sector within the country. Conversely, opportunities and threats represent external factors that may influence future developments, both domestically and internationally. This analysis aims to identify how existing strengths can be leveraged to seize opportunities and address potential threats. At the same time, weaknesses will be highlighted as they may be exacerbated by these external challenges and opportunities. The following table outlines the strengths, weaknesses, opportunities, and threats (SWOT) related to honeybee genetic improvement. This framework will serve as a foundation for formulating effective breeding strategies and programs. A detailed analysis of each component of the SWOT framework is provided in the table below.

Table 1. SWOT Analysis

Internal factors		External factors	
Strength	**Weakness**	**Opportunities**	**Challenges**
Genetic and breeding			
Honeybee population characterized at phenotypic level and some attempts at molecular level •Availability of some established breeding honeybee colonies in different research centers •The performance of local honey bee colonies tested and verified in different agro-ecologies	•Absence of improved honeybee breed •Inefficient utilization of research and queen rearing centers •No national beekeeping recording system •Low level of community involvement on genetic improvement •Poor and inefficient beekeeping extension system • Critical shortage of breeding and multiplication centers •Absence of honeybee breeders' (breed) society •Absence of indigenous honeybee breed conservation and multiplication centers •Lack of well-organized and consistent breeding program designed for honeybee improvement •The indigenous honeybee population are not adequately characterized specially by molecular tools •Poor intra and inter-institutional collaboration and partnerships •Brain wastage (lack of coordinating professionals) •Lack of application of biotechnological tools for genetic improvement and multiplication •Lack of quality standard (certification) regulatory mechanism •Limited application of climate smart beekeeping system	Availability of large number of honeybee population • Conducive climate that can support high yielding honeybee breeds • Approval of national animal breeding policy • Availability of research centers, HLI, LDI and other organization working of honey value chain • Presence of the Ethiopia Apiculture Development Association, professional associations (ESAP and EVA) • Growing demand for honey and bee products • Emerging of honey processing plants and commercial bee farms • Emerging of agro-industrial parks and industries • Attention given to the beekeeping sub-sector by donors and funding organizations	Climate change/ recurrent drought High prevalence of pests and predators Brain drain and rapid staff turnover

Capacity building			
Availability of researchers, experts and beekeeping technicians •Availability of structure for on farm breeding activities •Availability of research centers, and queen rearing centers	•Turnover of experienced breeders, experts and beekeeping technicians •Low level of breeding knowledge at expert, bee technician and farmers level •Lack of sufficient trained technician, experts and breeders •Inadequate integration and cooperation among MoA, research institutions, HLI and development Institutions •Insufficient budget allocation for management honeybee colony kept by research centers for breeding activities •Limited long-term training, skill and experience sharing •Limited monitoring and evaluation	The government's attention for human resource development The availabilities of HLI	In-adequate budgeting for genetic improvement and capacity building Limited focus for long- term training Inefficient procurement system for utilizing the available resources

4. Benchmarking

Countries are increasingly adopting benchmarking initiatives to assess the effectiveness of their honeybee breeding programs. Honeybee breeding strategies in developing countries encounter distinct challenges and opportunities. By implementing effective breeding techniques, it is possible to boost honey production, increase productivity, enhance disease resistance, improve bee temperament, and strengthen pollination services-all of which contribute to rural development. Below are the essential considerations and strategies for establishing successful honeybee breeding strategies in developing counties including Ethiopia.

1. Genetics diversity

Maintaining genetic diversity is crucial to avoid inbreeding, which can lead to poor colony performance and increased vulnerability to diseases. Breeding programs should focus on preserving local bee races and ecotypes before initiating breeding efforts (https://resources.beesfordevelopment.org/rc/breeding-honey-bees/). A global survey revealed that many countries are actively engaged in maintaining genetic diversity among honeybee populations through various methods, including controlled breeding and habitat conservation. Countries reported using scientific research as a primary strategy for conserving honeybees, followed by regulations on pesticide use and the protection of native breeds (Global Survey, 2018). This highlights the importance of genetic diversity in ensuring resilient bee populations.

2. Local adaptation

Breeding programs must consider the local environment, including climate, flora, and disease pressures. This ensures that selected traits are relevant to the specific challenges faced by beekeepers in the country. Research has shown that certain populations exhibit high survival rates against varroa infestations, highlighting the importance of local adaptations in breeding strategies (Pries et al., 2020).

3. Training and capacity building

Training local beekeepers and apiculture professionals in advanced breeding techniques, such as instrumental insemination or controlled mating practices and selective breeding is essential. This capacity building can help ensure that breeding efforts are scientifically

grounded and sustainable.

4. Community involvement

Engaging local communities, especially women and youth, in beekeeping can enhance participation and support for breeding initiatives. Programs should focus on inclusive practices that empower all stakeholders in the honey value chain.

4.1. Strategic Approaches

1. Assessment of Local Bee Populations

Conducting surveys to understand the existing honeybee races, and their performance traits is critical before starting a breeding program. This helps in selecting the best stock for improvement efforts (https://resources.beesfordevelopment.org/rc/breeding-honey-bees/)

2. Selection of Desirable Traits

Focus on traits such as honey production, productivity, disease resistance (e.g., Varroa mite resistance), and temperament. Regular evaluation of colonies based on these traits can guide selection processes.

3. Collaborative Breeding Strategy

Smaller operations may benefit from collaborating with other beekeepers or institutions to pool resources and genetic material, thereby enhancing the genetic base available for selection.

4. Implementation of Best Practices

Utilizing best management practices for pest control, nutritional needs, and hive management can significantly improve overall colony health and productivity (Farooq et al. 2007).

5. Monitoring and Evaluation

Establishing a robust monitoring system to evaluate the performance of selected breeding stocks over time is essential for continuous improvement and adaptation of breeding strategies (National Honeybee Breeding Strategy 2024-2029).

4.2. Overview of honeybee breeding experiences in different countries

Honeybee breeding practices differ markedly from one country to another, shaped by local environmental conditions, the species of bees present, and the unique objectives of beekeepers. These breeding experiences represent a fusion of traditional methods and

contemporary scientific techniques designed to improve bee health and productivity. As challenges like pests and environmental changes become increasingly complex, prioritizing sustainable and genetically diverse breeding practices will be crucial for the future of beekeeping globally.

Key Insights into Regional Honeybee Breeding Practices

Here are some important insights into honeybee breeding experiences from various regions:

1. Serbia

Breeding History and Practices: Serbia has a long tradition of beekeeping, with systematic honeybee breeding starting in the 1980s. The country primarily focuses on the native Apis mellifera carnica subspecies to preserve local genetic diversity. There are six selection centers in Serbia, and breeding programs are strictly regulated to avoid the introduction of non-native subspecies (Kaur et al., 2024). Recent studies have shown that honey bees bred in controlled environments differ morphologically from wild populations, highlighting the impact of artificial selection on natural variation (Kaur et al., 2024).

2. Germany

Organized Breeding Programs: Germany boasts a robust beekeeping community with nearly 90,000 beekeepers. The country has established organized breeding programs that emphasize traits beneficial for apiculture, such as honey yield and resistance to pests like the varroa mite. Economic aspects indicate that countries with structured breeding initiatives tend to have higher market prices for queen (Traynor, 2008). Research indicates that German breeders are increasingly focusing on genetic improvements through techniques like marker-assisted selection to enhance disease resistance and overall colony health.

3. European Union Initiatives:

The EU conducted a significant pilot study from 2018 to 2021 aimed at enhancing the resistance of honey bees to the varroa mite, a major threat to bee populations. This study involved collaboration among scientists, beekeepers, and breeder associations across 11 EU countries and highlighted the potential for selective breeding to develop varroa-resistant bees. The findings suggest that while selection is effective, it requires substantial investment and long-term commitment for success (European Commission, 2022).

4. Developing Countries

Caution in Breeding Initiatives: In many developing nations, it is crucial to conduct thorough surveys of local bee species and ecotypes before initiating breeding programs. This approach helps prevent the loss of indigenous genetic material, which can occur if non-native bees are introduced without proper assessment.

Focus on Local Needs: Breeders in tropical regions often prioritize different traits compared to temperate areas, reflecting local environmental challenges and market demands. For instance, honey yield and defensive behavior are commonly selected traits across various regions.

5. Global Trends

A comprehensive analysis of honey production trends from 1961 to 2017 indicated that while global honey production has increased significantly, regional disparities exist. For instance, Asia and South America have seen considerable growth in both the number of managed colonies and honey yields per colony. In contrast, North America and parts of Europe have experienced declines in these metrics (Phiri et al., 2022). This suggests that countries with proactive breeding programs may perform better in terms of production.

Resistance to Pests: The global spread of pests like the varroa mite has shifted breeding priorities towards developing bees that exhibit natural resistance mechanisms. This includes selecting for traits such as Varroa Sensitive Hygiene (VSH), which enhances the colony's ability to manage mite populations naturally.

Conservation Efforts: There is a growing recognition of the need for sustainable practices in honeybee breeding to conserve genetic diversity while meeting agricultural demands. This includes efforts to improve the attractiveness of endangered populations to local beekeepers.

Table 2. Comparative Analysis of Breeding Programs

Country/Region	Key Focus Areas	Notable Practices	Challenges
European Union	Varroa resistance, productivity	Selective breeding programs, funding for long-term studies	High costs, need for sustained support
Asia	Increasing colony numbers, yield improvement	Adoption of A. mellifera strains	Varied climatic conditions
North America	Declining colonies, need for disease management	Research on pest management techniques	Loss of colonies due to pests
Africa	Traditional vs. modern beekeeping practices	Transitioning from traditional to modern hives	Low productivity in traditional systems

5. Strategic Interventions

5.1. Genetic improvement, multiplication and conservation

The genetic improvement, multiplication, and conservation of honeybees are critical areas of research aimed at enhancing the resilience and productivity of bee populations. This involves various genetic techniques, breeding programs, and conservation strategies to ensure the sustainability of honeybee species. The honeybee breeding strategy is a systematic intervention that is intended to address the current situation and developed to guide the implementation of this process that would lead to a more productive beekeeping subsector. Honeybee breeding strategic interventions include inadequate characterization of local honeybees, low productivity and production of local honeybees, lack of genetically enhanced stock lines, limited genetic information (e.g. gene actions and inheritance of traits) to meet desirable traits like higher honey production, docility and healthier colonies, lack of central database and networking and capacity building. Although these are the identified strategic intervention areas in local honeybee genetic improvement, all

the issues cannot be addressed at a time. Some of the issues could be addressed in the short-term, others in medium-term and long-term plans as predicted in Table 3.

Table 3. Strategic intervention in short and medium term across the strategic objectives

Strategic issue	Strategic interventions		
	Short-term	Medium-term	Long-term
Genetic improvement			
Lack of organized attempt to develop a genetic improvement program to develop improved traits of local honeybee	Demand analysis for honeybee genetic improvement (to develop breeding program and multiplication) Phenotypic and molecular characterization of local honeybee ecotypes to explore diversity, identify traits of interest for further genetic improvement Identify the source of honeybee ecotypes/population for the initial stock Mapping location appropriate for selective improvement Design an appropriate breeding program suitable to improve local honeybee traits Establish a national honeybee breeding database system for progeny testing and feedback	Developing a national potential honeybee resource map Implement appropriate breeding program suitable to local honeybees Select breeder queens for progeny testing using the national breeding database Continue phenotypic and molecular characterization of Ecotypes/population to explore diversity, and identify traits of interest for further genetic improvement Production and selection of new generation produced based on selection criteria, identify candidate breeder queens	Continuous selection and evaluation for genetic improvement of local honeybee stocks Multiplication and utilization in a broad population
lack of skilled human power in advanced tools of stock improvement using AI	Short-term training in modern tools to fill skill gaps Start long-term specialized training of staff on AI	Long-term specialized training of staff Deliver effective technical and business training to all actors along Ethiopia's honey value chain	Continue specialized skill training for technicians and other support staff

Weak coordination modality and linkage among disciplines and with other stakeholders	Establish clear linkage modality among different stakeholders Strengthen linkage between MoA and other stakeholders Develop a share of responsibilities among institutions and other stakeholders towards common goals 50% government (MoA/ LDI budget line, ETB 100M/ year), 30% private (processors/agro-parks via 1% honey sales levy), 20% donors . Track via transparent platform with annual audits.	Establish information exchange platforms among MoA, research institutions and development Institutions Continue strengthening stakeholder linkage Evaluate the implementation, assess gaps (challenge) and modify the share of responsibilities among institutions and other stakeholders if necessary	Continue strengthening stakeholder linkage and platforms Continue evaluation of the implementation, assess gaps (challenge) and modify of share of responsibilities among institutions and other stakeholders if necessary
Poor infrastructure and facilities	Stablishing a nucleus breeding center for honeybees that can support genetic improvement programs and conservations Availing laboratory equipment, other facilities including PCR machines, genetic analyzers, Sequencers, HPLC, reagents and consumables 3 nucleus centers (Holeta, Gondar, Awassa) with 500 colonies each, budget ETB 50M (PCR, mating yards)	Strengthening of honeybee breeding and mating sites Keep improving and maintaining breeding and mating sites Continue availing of up-to-date laboratory facilities and equipment. 10 satellite sites via PPP;	Continue to maintain and modernize breeding sites with research infrastructures Continue availing of up-to-date facilities and equipment 20 centers by 2030. Secure funding via 5-year MoA grants (ETB 200M)
Lack of organized animal performance recording and feedback system	Improve the ICT service and infrastructure Starting to put in place an apiary data recording system at the beekeepers' level	Strengthen the ICT service and infrastructure Continuing in placing the apiary data recording system at the beekeepers' level	Continue upgrading the ICT service and infrastructure Continuing in placing the apiary data recording system at the beekeepers' level
Improved stock multiplication			

Insignificant attempt for multiplication of better-performing stocks	Optimization of protocol suitable for improved/better-performing stock multiplication such as isolated mating stations, drone flooding, closed population breeding and AI	Implementing the application of multiplication tools such as Isolated mating station, drone flooding, closed population breeding and AI (if possible)	Large scale application and encouraging private breeders in stock multiplication using isolated mating stations, drone flooding, closed population breeding and AI (if possible)
Conservation of genetic resources			
No attempt for conservation of local honeybee traits	Assess the status of local honeybee ecotypes/populations Assess ecotypes' economic and ecological importance (eg, disease resistance, adaptation to varying environments, etc.).	Design and apply appropriate means of conservation, improvement and sustainable utilization Establish in-situ areas for local honeybee conservation Monitor effective population size (Ne >500), using csd allele diversity (>20 alleles/population) and inbreeding coefficient (F<0.05). Protocols: Rotate drone sources across ecotypes, enforce 20% outcrossing annually, cryopreserve elite germplasm; trigger alerts if diversity drops 10%.	Continue utilization, stock maintenance, and conservation of genetically improved honeybee stocks Initiate identification and conservation of DNA of important improved stocks (e.g., genes of disease resistance, docility, and production using modern biotechnological tools)
Crosscutting and capacity building issues			

Weak design for gender disaggregate extension systems suitable for specific production systems	Assess and analyze the existing extension system Identifying constraints and opportunities for women's participation in honeybee genetic improvement and development Design a suitable gender disaggregate extension system for specific production systems Device suitable approach to enhance community involvement in a genetic improvement program	Apply suitable gender disaggregate extension system for specific production systems or agro-ecologies Implementing strategies to address the identified constraints and to take advantage of opportunities Test practiced extension system Apply a better approach to enhance community involvement in the genetic improvement program	Continue applying and testing the extension system and modify it if necessary Continue enhancing and testing the community involvement approach
Lack of efforts to reduce the influence of climate change/variability on honeybee genetics and a scarcity of technological choices to cope with climate change	Assessment of the impact of climate change/variability, adaptation and mitigation options Investigation on genetic improvement options for climate resilient honeybee stocks	Assessment of the impact of climate change/variability, adaptation and mitigation options Investigation of genetic improvement options for climate resilient in honeybee Design beekeeping integration measures that can reduce environmental changes	Continue assessment on the impact of climate change/variability and mitigation options for beekeeping Apply genetic improvement options for climate resilient strains/stocks Practice integration of beekeeping in environmental conservation programs
Lack of skilled human power on bee breeding	Short-term training for selection, mating system mating control, and selective breeding programs for researchers, technicians and bee experts	Continue long-term specialized training for special honeybee breeding team (researchers) Specialized skill training for technicians and experts in breeder queen rearing and AI of breeder queens Deliver effective technical and business training to all actors Involving in honeybee queen rearing and bee breeding	Continue long-term specialized training for special honeybee breeding team (researchers) Continue specialized skill training for technicians and other actors involved in honeybee breeding

6. Strategies for Designing and Implementing Breeding Programs

Designing and implementing effective breeding programs requires a multifaceted approach that encompasses various strategies and considerations. Implementing a successful breeding program involves careful planning, clear objectives, accurate data management, effective mating strategies, capacity building, strong institutional support, long-term commitment, and regular evaluation. By integrating these strategies, genetic gains can optimize while ensuring sustainability in beekeeping production systems. The objective of this section is to provide a technical/operational guide for the implementation of the strategy. Bee breeding strategies are essential for improving honey bee populations, focusing on traits such as productivity, temperament and health. During the development of this breeding strategy, it is clear breeding has different approaches to selection and places different emphasis on selection traits. Thus, the steps outlined for designing breeding programs do not strictly follow the conventional procedure but more of the practical aspects could be modified based on the Ethiopian beekeeping context.

The breeding program is a base to create genetic change in the honeybee population to enhance the contribution of the sector to the national economy and benefit the beekeepers and the respective actors in the bee product value chain. In addition, the breeding program should address clear breeding goals which include economically important traits and other related adaptation traits. There are two honeybee breeding strategies, open and controlled breeding systems, each with its methodologies and goals.

6.1. Open Breeding Systems

In open breeding systems, queens mate naturally with drones available in their vicinity. While this method is more accessible for beekeepers without advanced resources, it offers less control over genetic outcomes compared to a controlled breeding system (instrumental insemination). The success of open mating is influenced by local environmental conditions and the ratio of desirable drones in the area. Collaborations among local beekeepers can enhance genetic diversity by introducing desirable traits across populations.

6.2. Controlled Breeding Systems

Closed breeding systems typically use instrumental insemination (artificial insemination) to control the mating between selected queens and drones. This technique requires ad-

vanced training and specialized equipment and is rapidly gaining popularity. Closed breeding systems allow breeders to rapidly produce colonies with desirable genetic traits by controlling mating between queens and drones and rearing new queens and drones from these crosses. However, a closed breeding program is not suggested in the medium-term strategic intervention to bring genetic change to Ethiopia's beekeeping production. Nevertheless, it could not be ignored in the long-term strategic intervention to improve the sector's productivity rapidly.

6.3. Design options for selection programs

Prioritization of traits

Which trait one should choose to improve is the most important question, as it determines the direction in which traits change over generation by selection. It is the first step towards the initiation of a breeding program, together with the recording of these traits to allow selection. Prioritization is required since resources are limited and breeding programs cannot be developed for all traits. Prioritization will be based on honey production, docility (temperament), disease tolerance, swarming tendency, interest in the conservation of native and local populations, local adaptation and overall vitality as prime traits of interest. The prioritization could be at the national or regional level.

Standardize queen evaluations with quantitative scoring (1-10 scale), including honey yield (kg/colony/year), hygienic behavior (% diseased brood removed in 24h), and temperament (sting score during inspections). Apply BLUP models adjusted for environmental effects, supported by annual progeny testing of 200-1,000 colonies to track genetic gain (target: 1-2% annual improvement per trait). Mandate replicated field trials (n=30/colony line) across agro-ecologies, incorporating DNA markers for traits like Varroa resistance.

Selection criteria for honeybee breeding

Honeybee breeding focuses on enhancing economically useful traits to improve colony performance and resilience. The selection process requires careful consideration of various factors. Here are the primary selection criteria used in honeybee breeding:

Economically useful traits

- Honey production: The quantity of honey produced is a key trait for commercial beekeepers. Colonies that consistently yield high amounts of honey are prioritized.
- Temperament: A calm and manageable temperament is essential for beekeepers' safety and ease of handling. Aggressive bees are often culled from breeding programs.
- Hygienic behavior: This trait refers to the bees' ability to detect and remove diseased broods, which helps maintain colony health. Colonies exhibiting strong hygienic behavior are favored.

Environmental adaptability

- Climate suitability: Different bee strains may be better suited to specific climates.
- Local conditions: The specific conditions of the apiary, including the availability of forage and local pests, influence breeding decisions. Beekeepers must consider how these factors affect colony performance.

Implement tiered thresholds for selection:

Tier 1 (Pre-select): Top 25% honey yield (>20 kg/colony), low swarming (<10% rate).

Tier 2 (Candidates): Hygienic score >70%, docility score <2 stings/inspection, verified through 3-site progeny tests (n=10 daughters/colony).

Maintain pedigrees using queen tagging or microchipping.

Designing breeding programs

Designing effective breeding programs is crucial for achieving genetic improvement in livestock. This process involves multiple steps, including defining breeding objectives, selecting appropriate traits, and determining the structure and strategy for the breeding scheme. The designing process should be participatory and needs to get approval from the different stakeholders including the beekeepers.

Definition of breeding goal

Breeding programs need to be designed to address both the objectives of the beekeepers and the national strategy including the market requirements. The definition of breeding

objectives includes the identification of traits (honey production efficiency, temperament (docility, resistance to pests and diseases), hygienic behavior and economic values, as well as the direction of selection needed to determine whether to increase or decrease certain traits. Economic values can be estimated through participatory consultation of beekeepers and end markets. This approach is suitable for community-based programs where selection programs on scientific index selection based on breeding values may not be feasible. For this breeding program, bio-economic models in combination with a participatory approach could be adopted to define breeding goals. Traits with higher economic values are considered the breeding goal traits.

Relative economic weights of traits

Relative economic weights are crucial in animal breeding as they quantify the economic impact of changes in specific traits. This is defined as the additional gain or loss from a unit change in a trait, relative to other traits within a defined production system. Relative weights can be derived using participatory approaches by asking beekeepers to allocate pebbles or seeds to the traits according to their preferences for traits. However, this method provides only relative weights, not relative economic weights. The calculation of REWs allows breeders to create economic selection indexes that guide breeding decisions effectively. These weights help breeders prioritize traits based on their contribution to profitability in production systems.

Develop a bio-economic model using net present value (NPV) of genetic gains:

Prioritize traits as follows: honey production (REW = 0.6), docility (0.2), disease tolerance (0.2). Project ROI at 15-20% over 5 years from a 10% yield increase, validated through participatory beekeeper surveys (100 points allocated across traits).

Designing breeding schemes

Designing effective honeybee breeding programs involves a systematic approach to selecting and improving desirable traits within bee populations. This process can be categorized into closed and open breeding systems, each with distinct methodologies and objectives. Open breeding schemes are flexible and accessible methods for beekeepers aiming to enhance their honeybee populations' genetic quality through natural mating practices.

By carefully selecting breeding stock, managing mating environments, and continuously evaluating performance, beekeepers can achieve significant improvements in their colonies' health and productivity. An open breeding scheme is suggested for medium-term intervention for beekeepers without specialized resources is suggested. The scheme involves rearing queens from top-performing colonies and introducing desirable drone-producing colonies to enhance genetic diversity in the mating pool. However, the success could be influenced by local environmental factors and the proportion of desirable drones available for mating.

Implement a 12-month open-system cycle:

- Months 1-2: Select and graft from top 50 colonies.
- Months 3-4: Queen mating via drone flooding during peak forage (e.g., post-rainy season).
- Months 5-8: Progeny evaluation.
- Months 9-12: Culling and selection for next cycle.

Target 1-year generation interval (queen lifespan: 1-2 years), with 4-6 mating flights per queen to balance polyandry risks

Steps in an open breeding scheme for honeybees

An open breeding scheme for honeybees involves several structured steps aimed at improving the genetic quality of bee populations through natural mating. Below are the key steps involved in this process:

1. Establishing a base population

- Selection of colonies
- Start with a large population of colonies, ideally around 200, to ensure genetic diversity. From this pool, select the top-performing colonies based on desirable traits such as productivity, temperament and disease resistance.
- Initial screening
- Conduct a pre-selection test to narrow down the number of colonies to about 75,

and then further screen to identify the top 30-50 colonies for breeding purposes.

2. Queen rearing

• Grafting

• Produce queens from the selected top colonies by grafting larvae into queen cells. This is done to ensure that the new queens carry the desired traits.

• Mating preparation

• Transfer mature queen cells to nucleus colonies where they will be mated. Ensure these colonies are well-fed and populated with nurse bees to support the developing queens.

3. Natural mating

• Drone introduction/flooding

• Introduce drone-producing colonies in the vicinity to increase the pool of desirable drones available for mating. This step is crucial as it enhances the chances of queens mating with genetically favorable drones.

• Mating area management

• Utilize isolated mating areas if possible, which helps control the environment and increases mating success rates by reducing competition from less desirable drones.

4. Evaluation and selection

• Performance testing

• After queens have mated and begun laying eggs, evaluate their performance based on established breeding objectives, such as honey production, temperament, and disease resistance.

• Culling poor performers

• Remove any queens or colonies that do not meet performance standards from the breeding pool to maintain high genetic quality.

5. Continuous improvement

• Iterative process

• Repeat the selection and breeding process annually. This ongoing evaluation helps

maintain selection pressure on traits of interest and improves overall colony performance over time.

6. Evaluation and record keeping

- Maintain meticulous records of colony performance, behaviors, and health conditions throughout the active season. This data is critical for making informed selections and tracking improvements over time.

Pre-evaluation of breeding schemes

The breeding program needs to be evaluated before implementation for its genetic and economic feasibility using appropriate tools. The selection of schemes would be based on their return to investment and operational feasibility and other criteria such as the need for conservation (for instance community-based breeding programs are suitable for in situ conservation strategy).

Organization and operation of breeding programs

Recording scheme and database system

Honeybee breeding schemes have evolved significantly, incorporating advanced genetic evaluation methods and comprehensive data recording systems.

Data Collection and Recording: Breeders are encouraged to implement a routine recording practice that captures essential data on various traits, including honey production, brood patterns, and resistance to pests and diseases. Each record should include details such as the date, apiary location, colony ID, queen ID, and the assessor's identity. This systematic approach helps in tracking performance over time and across different environments. A database system is established for each breeding program.

Develop a cloud-based system (KoboToolbox-integrated SQL database) capturing:

- Queen/colony ID, lineage (sire/dam csd alleles)
- Hybridization flags (molecular SNP markers)
- Performance data (trait scores, yields)

Short-term rollout: Pilot with 5,000 records, linked to MoA ICT for real-time progeny feedback.

Association launch (2026): Under MoA oversight with 500 members (beekeepers, researchers); establish bylaws for queen certification, annual congresses, and district chapters. MoA provides seed funding (ETB 10M); association manages dissemination (10,000 queens/year).

Other organizational considerations

- The geography of the breeding program needs to be delineated. The geographic description includes the districts, kebeles, honeybee cattle population, the number of participants that need to be recorded.
- Awareness creation is required among the communities and other stakeholders in the program.
- Consultative meetings with communities and stakeholders, and a fully participatory approach throughout the period of the program need to be followed.
- Training of communities and experts on animal breeding principles and methods.
- Selection of villages and organization of cooperative breeding groups is required for community-based programs.

Annual breeding plan

An effective annual breeding plan for honey bees requires careful planning and execution. By focusing on trait selection, rigorous evaluation methods, and strategic breeding practices, beekeepers can enhance their colonies' productivity and resilience. Continuous monitoring and adaptation are key to achieving long-term success in honey bee breeding programs.

Key components of a breeding plan

1. Trait selection

Desirable traits: Beekeepers often focus on traits such as honey production, temperament, disease resistance. Selecting these traits helps improve the overall performance of the colonies.

Local adaptation: Many beekeepers aim to develop locally adapted stocks that perform well in specific environmental conditions. This involves understanding the unique stress-

ors faced by bees in different regions, such as floral availability and pest pressures.

2. Evaluation methods

Performance monitoring: Regular inspections and meticulous record-keeping are essential for evaluating colony performance. This includes tracking honey production, brood viability, and overall colony behavior throughout the active season.

3. Breeding strategies

Closed vs open systems: Closed breeding systems use controlled mating to maintain genetic integrity, while open systems allow for more genetic diversity but may introduce undesirable traits. Beekeepers must choose a strategy that aligns with their goals.

Culling practices: To maintain high standards, beekeepers should cull queens or entire colonies that exhibit poor performance or undesirable traits, thereby refining the breeding stock over time.

Implementation steps

Initial stock assessment: Begin by evaluating existing colonies to identify those with desirable traits.

Queen rearing: Raise queens from high-performing colonies, ensuring they are mated with drones from similarly high-quality stocks to enhance genetic quality.

Regular performance reviews: Throughout the season, assess the performance of new generations against established benchmarks to ensure continuous improvement.

Adaptation and adjustment: Be prepared to adjust breeding objectives based on environmental changes and colony performance outcomes.

Monitoring and evaluation

Effective monitoring and evaluation (M&E) of breeding programs are essential to ensure that desired traits are selected and improved over time. The annual plan and the life-of-program plan are detailed in a logical framework. A monitoring and evaluation plan is set and strictly followed. A key component of the M and E is genetic progress achieved (genetic gain) and the expansion of the scope of the program (dissemination of improved genetics to communities).

Key Performance Indicators (KPIs):

- Operational sites (+2/year target, baseline: 2 centers)
- Equipment utilization (>80%)
- Maintenance cost (<ETB 500/colony)
- Genetic gain (% trait improvement/year)
- Dissemination (50,000 improved queens/year)
- Genetic diversity (heterozygosity >0.8)
- ROI (>15%)
- Colony survival (>85%)

Review programs:

- Quarterly: Progress KPIs via dashboard
- Bi-annual: Genetic audits through database
- Annual: Full review with gain calculations
- 3-year: ROI assessment and strategy reset

Implement using logical framework with baselines, annual LDI audits, and participatory beekeeper input via independent LDI panel.

Stock maintenance

Improved stocks of honeybees must be maintained. The best way to maintain improved strains of bees is by establishing long-term breeding programs that continue to select and replace stock. The genetic improvement gained from selective breeding can be rapidly lost if selection is relaxed. To be successful, good methods of selection and mating control must be employed, and these actions must be applied continuously generation after generation.

7. Roles and Responsibilities of Institutions

Table 4. Roles and responsibilities of institutions

Stakeholders	Roles and Responsibilities
Ministry of Agriculture	Develop a system that ensures integration and coordination of Stakeholders engaged on honeybee breed improvement activities Build human and infrastructural capacity required for genetic improvement Build capacity for supplying, distributing and marketing of inputs and out puts to ensure success of genetic improvement and follow up the implementation of the strategy Promote better technologies and training services Establish a system that ensures quality standard for product supply Establish a system that ensures access to quality veterinary services to improve the prevention and timely control of animal disease that could influence the success of genetic improvement Conduct quarantine on import and export of livestock, fish and their products; prevent communicable livestock diseases and the outbreak of migratory parasites
Livestock Development Institute and Holeta Bee Research Center	Prepare and implement national honeybee breeding programs and follow up of implementation of strategies and program Establish, organize and lead honeybee breeding stations required for genetic improvement Build human and infrastructural capacity required for honeybee genetic improvement Establish national honeybee breed recording system, set up database, Collect breed improvement data, develop webpages and follow up its implementation Run breeding program, analyses of the data and genetic gain, the measure productivity and provide feedback to users Undertake research on honeybee genetic improvement Promote honeybee genetic improvement activities on public media by developing webpages, fliers, posters and through other knowledge sharing means and follow up its outcome Establish synergy between the Institute and regional operation system and provide technical support on honeybee genetic improvement Provide technical trainings for beneficiaries on improved breed; organize workshops, symposia and seminars concerning honeybee genetic improvement, facilitate experience sharing programs among stakeholders involved in honeybee genetic improvement

National Animal Health Institute	Evaluate and certify health of honeybees used for genetic improvement Undertake and monitor honeybee health programs
Ethiopian Institute of Agricultural Research	Generate and adapt honeybee breeding technologies Coordinate honeybee genetic improvement research activities conducted at research centers, higher learning institutions, and others Development of breeding program, undertake suitability mapping for honeybee genetics and analysis of breeding program Establish an effective system for coordination between the federal research centers and other stakeholder involved on honeybee breed improvement Collect, organize and disseminate information on honeybee genetic improvement research activities and results available in the country or abroad, and develop and coordinate information exchange mechanisms
Regional Research Institute	Generate and adapt honeybee breeding technologies Develop breeding program, undertake suitability mapping for honeybee genetics and analysis of breeding program Collect, organize and disseminate information on honeybee genetic improvement
Ethiopian Biodiversity Institute	Initiate policy and legal proposals on the conservation and sustainable utilization of the honeybee genetics Survey and explore the diversity and distribution of the country's honeybee genetic resources, identify and characterize the status of breeds for conservation and sustainable use status Develop means of conservation by utilization
Ethiopian Biotechnology Institute	Support in introduction, optimization and application of honeybee biotechnologies
Higher Learning Institutions	Undertake honeybee genetic improvement research Produce competent human power and involve in human capacity building Participate on implementation and analysis of breeding program
Regional, zone and woreda livestock development	Implement honeybee breeding strategies and programs Facilitate Land and finance for improved honeybee colony strengthening and establishment Engage on breed improvement, multiplication and conservation Build human and infrastructural capacity required for genetic improvement

Agricultural Investment Agency	Identify agricultural investment potential lands Transfer investment lands to investors Bridging role between private investors and out growers Provide necessary information and advisory services to agricultural investors
Agricultural Transformation Institute	Provide technical support on honeybee genetic improvement
Private sectors	Involve on implementation of breeding program and multiplication of improved genotypes Participate on service delivery (AI Delivery) Participate on input and output production and delivery
Development Partners	Technical and financial support on honeybee genetic improvement

8. Expected Outputs

- The strategy is expected to resolve the current disorganized honeybee breeding initiatives which would improve the efficiency and effectiveness of genetic improvement initiatives
- Ongoing fragmented, project-based and research-based breeding activities will be transformed into sustainable breeding programs
- Conservation-based genetic improvement through scientific selective breeding programs of the adapted indigenous honeybee genetic resources would increase their economic contribution and their survival as breeds.
- The research and development institutions will be integrated and work towards the same breeding goal.
- Involvement of the private sector in genetic improvement will increase and job opportunity created for small businesses delivering improved genetics.

9. Target Groups and Beneficiaries

The direct beneficiaries of this strategy will be smallholder beekeepers and commercial beekeepers especially those participating in the pilot genetic improvement scheme and will be provided with extension services on honeybee breeding, colony management to

improve production, efficiency and profitability of their honeybee colonies. Technical institutions such as MoA, research institutions, higher learning institutions and Queen Rearing centers are beneficiaries of the genetic improvement strategies and programs, since they are expected to participate in the process of developing and later implementing the national strategy and programs. Moreover public private companies' for instance private queen suppliers, honey collectors, processors, consumers, jobless youth and others will involve and benefited throughout the implementation of the strategy.

10. Monitoring and Evaluation

Progress and achievements of outputs will be periodically monitored and evaluated through a participatory approach. Special attention will be given to the development and effective implementation of customized breeding programs, as well as the effectiveness of the institutional framework, including the convergence and coordination among stakeholders. Furthermore, the key deliverables listed in the accompanying table will also be monitored and evaluated according to their respective target delivery timelines.

This Monitoring and Evaluation (M&E) framework is designed to track the implementation of the Honeybee Breeding Strategy. It ensures that strategic interventions in genetic improvement, multiplication, and conservation are translated into measurable genetic gains and economic benefits.

10.1. Strategic M&E Roadmap: Major Milestones

The implementation is divided into three phases, each marked by critical milestones.

Table 5. Strategic M&E roadmap: Major Milestones

Phase	Timeline	Major Milestones
Short-Term (Foundational)	Year 1-2	National Honeybee Breeding Database (Kobo-integrated) launched. Phenotypic/Molecular characterization of top 3 ecotypes completed. Three Nucleus Breeding Centers fully equipped and stocked.

Medium-Term (Operational)	Year 3-5	10 Satellite Mating Sites established via PPP. BLUP (Best Linear Unbiased Prediction) models applied to selection. 1st Generation of "Improved Stock" (G1) validated through multi-site trials.
Long-Term (Sustainable)	Year 6-10	National Bee Breeders Association established and certifying queens. 20 Breeding Centers operational nationwide. Measurable 10% increase in national honey yield attributed to genetics.

10.2. Key Performance Indicators (KPIs)

The success of the strategy will be measured against these specific, quantifiable metrics.

A. Genetic Improvement & Conservation

- Genetic Gain: Annual % increase in honey yield per colony in the breeding program (Target: 1–2% per annum).
- Trait Standardization: % of breeder queens scoring >7.0 on the 1-10 quantitative scale for docility and hygienic behavior.
- Genetic Diversity: Effective population size (Ne) maintained above 500 and csd allele diversity maintained at >20 alleles per population.
- Inbreeding Coefficient: Average F value kept below 0.05 across nucleus colonies.

B. Infrastructure & Multiplication

- Capacity Utilization: % of nucleus center facilities (PCR, mating yards) operating at >80% capacity.
- Stock Dissemination: Number of improved/certified queens distributed to beekeepers annually (Target: 50,000 by Year 5).
- Site Density: Number of operational satellite sites (Target: 10 by Year 5; 20 by Year 10).
- Private Sector Involvement: Number of private breeders/multipliers licensed and utilizing drone-flooding protocols.

C. Economic & Human Capacity

- Return on Investment (ROI): Realized net present value (NPV) of genetic gains (Target: 15–20% ROI over 5 years).
- Skill Acquisition: Number of technicians certified in Artificial Insemination (AI) and grafting (Target: 50+ specialized staff).
- Gender Parity: % of women participating in the genetic improvement value chain (Target: 30% increase in participation).

10.3. Monitoring & Evaluation Matrix

This matrix details how data will be collected and who is responsible.

Table 6. Monitoring and Evaluation Matrix

Intervention Area	Key Performance Indicator (KPI)	Frequency	Data Source / Method	Responsibility
Characterization	# of ecotypes mapped and DNA-profiled	Bi-Annual	Lab Reports / Resource Map	EIAR / LDI
Breeding Goal	Average Honey Yield (kg/ colony/year)	Annual	Apiary Records / Database	LDI / Research Centers
Multiplication	# of queens produced from selected lines	Quarterly	Production Logs	Nucleus Centers
AI & Skill Gap	# of staff trained & active in AI	Annual	Certification Records	MoA / HLIs
Funding	% of budget secured (50% Gov, 30% Private, 20% Donor)	Annual	Audit Reports / Sales Levy	MoA Finance
Conservation	Heterozygosity & Allele counts	Every 2 Years	Molecular Analysis	Bio-Tech Institute

10.4. Specialized M&E Protocols

A. The Genetic Audit (Every 2 Years)

- To ensure conservation is not sacrificed for production, the Ethiopian Biodiversity Institute will conduct a genetic audit.
- Trigger: If genetic diversity drops by 10%, a mandatory “outcrossing protocol” will be triggered, requiring the rotation of drone sources from different ecotypes.

B. Participatory Performance Review (Annual)

Since beekeepers are the end-users, an annual "Breeder-Beekeeper Congress" will be held.

- Method: Beekeepers will use "Pebble Distribution" or survey tools to score the "Improved Stock" against "Local Stock" on traits like docility and swarming.
- Impact: This qualitative feedback will adjust the Relative Economic Weights (REW) used in the selection index for the following year.

C. Infrastructure Maintenance Monitoring

- Baseline: 3 Nucleus Centers.
- KPI: Equipment downtime. If laboratory equipment (Sequencers, HPLC) is down for >30 days, a Maintenance Gap Alert is sent to the MoA to reallocate the ETB 100M/year budget line.

10.5. Institutional Coordination Scorecard

To monitor the Weak Coordination issue identified in the strategy, an annual scorecard will be generated based on:

1. Data Sharing: Does the LDI receive records from Regional Research Institutes on time? (Target: 100%).
2. Joint Planning: Number of consultative meetings held between MoA and Private Processors regarding the 1% honey sales levy.
3. Extension Linkage: % of Woreda experts who have received Breeding Strategy Training.

10.6. Reporting Schedule

- Quarterly Progress Dashboard: Focuses on operational KPIs (Colonies, queens, training).
- Annual Strategy Review: Focuses on genetic gain calculations and budget utilization.
- 3-Year Impact Assessment: Focuses on ROI, national honey production trends, and climate resilience of the selected stocks.

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