

Review Article

Genetic diversity, adaptive variation, health challenges and conservation priorities of native honey bees *Apis mellifera intermissa* and *Apis mellifera sahariensis* in North Africa: a critical review

Running Head : *Diversity of North African Honey Bees*

Noureddine Adjlane^{1,2}, Soumeiya Kaouche^{1,2}, Nizar Haddad³

¹ Department of Agronomic Sciences, Faculty of Sciences, University of Boumerdes

² Laboratoire de Biologie et de physiologie animale, ENS de Kouba, Alger

³ Food and Agriculture Organization (FAO), Kingdom of Saudi Arabia

***Corresponding Author:** Noureddine Adjlane, Department of Agronomic Sciences, Faculty of Sciences, University of Boumerdes noureddine.adjlane@univ-boumerdes.dz.

Article history: Received: February 04th 2026 ; Revised: March 22nd 2026; Accepted: June 22nd 2026

Abstract

Honey bees (*Apis mellifera*) represent one of the most important pollinator species worldwide, contributing substantially to ecosystem stability, agricultural productivity, and food security. North Africa harbors two native honey bee subspecies, *Apis mellifera intermissa* and *Apis mellifera sahariensis*, which have evolved under contrasting Mediterranean and Saharan environmental conditions. These subspecies represent valuable genetic resources characterized by specific adaptive traits related to thermal tolerance, resource exploitation, and colony survival under stressful environments. This review provides an integrated synthesis of current knowledge on the genetic diversity, population structure, adaptive characteristics, health constraints, and conservation perspectives of these two North African honey bee subspecies. Previous studies have demonstrated that both taxa belong mainly to the African evolutionary lineage (lineage A), while also revealing substantial geographic variation and complex patterns of gene flow influenced by natural exchanges and modern beekeeping practices. Beyond summarizing existing results, this review highlights the interactions between genetic background, environmental adaptation, pathogen pressure, and anthropogenic impacts. Available evidence suggests that local adaptation represents a major component of colony resilience, but that increasing threats, including *Varroa destructor*, associated viruses, nutritional stress, pesticides, climate change, and uncontrolled genetic introgression, may compromise the long-term persistence of native populations. Future conservation programs should integrate genomic monitoring, protection of local genetic resources, sustainable breeding strategies, and improved management practices adapted to North African apicultural systems. Preserving *A. m. intermissa* and *A. m. sahariensis* is essential not only for maintaining honey bee biodiversity but also for securing pollination services and ecological stability in a region highly exposed to environmental change.

Keywords: *Apis mellifera intermissa*; *Apis mellifera sahariensis*; genetic diversity; adaptation; *Varroa destructor*; conservation; North Africa.

المخلص:

تُعدّ السلالتان المحليتان لنحل العسل في المغرب العربي، النحلة التلية والنحلة الصحراوية، من المكونات الأساسية للتنوع الحيوي في تربية النحل بشمال إفريقيا. وتُظهر هذه التجمعات تكيفات وراثية ومورفولوجية وفسولوجية وسلوكية خاصة مع بيئاتها المختلفة، حيث تنتشر إ. م. بينتيرميسا في المناطق المتوسطية وشبه الجافة، بينما تتكيف إ. م. ساهارينسيس مع الظروف الصحراوية القاسية. وتلعب هاتان السلالتان دورًا محوريًا في تلقيح المحاصيل الزراعية والحفاظ على التوازن البيئي. تستعرض هذه المراجعة المعارف الحالية حول التنوع الوراثي والبنية الوراثية للتجمعات، والصفات المورفومترية والتكيفية، وأهم التهديدات المرضية، إضافة إلى استراتيجيات الحفظ. كما نناقش تأثيرات التهجين، وتكثيف الممارسات في تربية النحل، والتغيرات المناخية، والضغوط البيئية على سلامة هذه السلالات وقدرتها على الصمود. ويُولى اهتمام خاص لدور الطفيليات (وخاصة *V. destructor*) والعوامل الممرضة المرتبطة بها، وكذلك للجهد الغذائي، في تدهور صحة الطوائف. وأخيرًا، نقترح مقاربات متكاملة للإدارة والحفظ تجمع بين استراتيجيات الحفظ في الموقع وخارجه، والمراقبة الوراثية، واعتماد ممارسات تربية نحل مستدامة، وتأمين الأنماط البيئية المحلية. إن الحفاظ على هذه السلالات المتوطنة من نحل العسل يُعدّ أمرًا ضروريًا ليس فقط لصون التنوع الحيوي الإقليمي، بل أيضًا لضمان استمرارية خدمات التلقيح والاستدامة الزراعية على المدى الطويل في النظم البيئية لشمال إفريقيا.

الكلمات المفتاحية: *Apis mellifera intermissa*؛ *Apis mellifera sahariensis*؛ التنوع الوراثي؛ المورفومتريا؛ *Varroa destructor*؛ الحفظ؛ شمال إفريقيا

Introduction

Honey bees (*Apis mellifera*) are among the most ecologically and economically important pollinators worldwide. Through their contribution to the reproduction of wild plants and cultivated crops, they play a central role in maintaining biodiversity and supporting agricultural systems (Klein et al., 2007). Their pollination activity is particularly important for fruit, oilseed, and vegetable production, making honey bee conservation closely linked to global food security and ecosystem functioning. North Africa represents a unique region for honey bee diversity because of its complex environmental gradients, ranging from Mediterranean ecosystems in the north to extremely arid Saharan environments in the south. These contrasting habitats have shaped the evolution of two native subspecies: *Apis mellifera intermissa* (Tellian bee) and *Apis mellifera sahariensis* (Saharan bee).

Apis mellifera intermissa is distributed mainly across northern Algeria, Morocco, and Tunisia, where populations experience Mediterranean and semi-arid climatic conditions. This subspecies is characterized by several traits considered favorable for survival under variable environments, including efficient exploitation of floral resources, high defensive behavior, and tolerance to local climatic constraints (Haddad et al., 2018). In contrast, *Apis mellifera sahariensis* occupies Saharan and pre-Saharan regions and represents one of the most specialized honey bee populations adapted to extreme arid environments. Its survival depends on a combination of physiological and behavioral mechanisms allowing colonies to cope with high temperatures, irregular floral resources, and prolonged periods of environmental stress (Haddad et al., 2017).

Although numerous studies have investigated African honey bee diversity, available information remains fragmented among different research fields. Genetic studies have mainly focused on phylogeography and population structure, whereas morphological and physiological studies have addressed adaptation mechanisms, and pathological studies have examined colony health independently. A comprehensive synthesis integrating these dimensions in the specific context of North African native subspecies remains limited. The objective of this review is therefore to provide a critical synthesis of current knowledge on *A. m. intermissa* and *A. m. sahariensis* by examining the relationships between genetic diversity, adaptive traits, health challenges, and conservation needs. Rather than only describing differences between subspecies, this review discusses how evolutionary history, environmental conditions, and human activities interact to shape the present status and future prospects of these valuable genetic resources.

Understanding these interactions is particularly important because honey bee populations are currently exposed to multiple interacting pressures. Worldwide, colony health is threatened by parasites such as *Varroa destructor*, associated viral infections, microsporidian diseases, pesticide exposure, habitat degradation, and climate change (Adjlane et al., 2018; Doublet et al., 2015). In North Africa, these pressures may be amplified by environmental fragility and by intensive beekeeping practices involving colony movements and queen exchanges.

Consequently, the conservation of native North African honey bees requires approaches that combine genetic preservation, ecological management, and sustainable apicultural practices. Protecting these locally adapted populations represents not only a biodiversity objective but also an essential component of maintaining resilient pollination systems under future environmental change.

Genetic diversity and population structure

1 Evolutionary lineages and molecular diversity

Molecular approaches, particularly mitochondrial DNA analysis of the COI–COII intergenic region, have provided fundamental information about the evolutionary history and diversity of North African honey bees. These markers have confirmed that populations of *A. m. intermissa* and *A. m. sahariensis* belong mainly to the African evolutionary lineage (lineage A), which distinguishes them from European lineages M and C (Franck et al., 2001; Haddad et al., 2015).

Studies conducted in Algeria have revealed considerable mitochondrial diversity within native populations. Analysis of the COI–COII region identified numerous haplotypes, including several previously undescribed variants, indicating that Algerian honey bees represent an important reservoir of genetic diversity (Bouga et al., 2011). The presence of common haplotypes shared between geographically distant populations suggests that some ancestral genetic components are widely distributed across North Africa. However, the interpretation of mitochondrial diversity should be

approached carefully because mitochondrial markers represent only maternal inheritance and do not fully describe nuclear genetic variation.

Recent studies based on complementary markers, including microsatellites and genomic approaches, indicate that population differentiation is influenced by both ecological gradients and human-mediated movements. Therefore, current evidence suggests a complex evolutionary pattern combining historical adaptation, geographic structure, and recent gene flow.

Differences in COI–COII structural patterns, including P0Q, P0QQ, and P0QQQ variants, further support the existence of genetic variability among North African populations. Nevertheless, additional genome-wide studies are still required to determine which genomic regions are associated with local adaptation and ecological specialization.

2 Population structure and hybridization

The population structure of North African honey bees reflects the combined influence of geography, environmental conditions, and beekeeping practices. Studies using microsatellite markers have suggested differentiation between Saharan populations of *A. m. sahariensis* and Tellian populations of *A. m. intermissa*, with the Atlas Mountains acting as an important geographic barrier (Barour et al., 2011).

However, this differentiation is not absolute. Several studies have detected genetic admixture between populations, particularly in regions where colony movements and queen exchanges are frequent. Such patterns indicate that human activities have modified natural population boundaries by increasing gene flow between previously separated groups.

The available evidence suggests that hybridization mainly occurs between African populations rather than through extensive introgression from European lineages. Nevertheless, the magnitude and biological consequences of this gene flow remain insufficiently resolved. From a conservation perspective, genetic mixing should not automatically be considered harmful because gene flow may increase genetic variability. However, uncontrolled introgression may also reduce locally adapted gene combinations that contribute to survival under specific environmental conditions. Future conservation programs should therefore aim to balance genetic diversity maintenance with preservation of regional adaptation.

Morphometric and adaptive traits

1 Morphometric diversity and wing geometry

Morphometric analyses have historically represented one of the main approaches for identifying honey bee subspecies and describing geographical variation within *Apis mellifera*. Traditional measurements, including body size, proboscis length, thorax dimensions, and wing parameters, have contributed to the characterization of North African honey bees. However, these approaches often show overlapping phenotypes between populations, limiting their ability to clearly separate closely related subspecies (Ruttner, 1988).

In *A. m. intermissa* and *A. m. sahariensis*, classical morphometric studies generally indicate relatively small differences between populations, suggesting that environmental variation and gene flow may contribute to continuous phenotypic variation rather than strict morphological boundaries (Bendjedid & Achou, 2014; Abed et al., 2021).

Geometric morphometric approaches based on wing landmark configurations have provided a more detailed understanding of population differentiation. These analyses consider the relative position of wing veins and are less affected by overall body size variation. Several studies have reported differences in wing shape associated with climatic conditions and geographical origin.

Saharan populations of *A. m. sahariensis* frequently display wing configurations characterized by longer and narrower shapes, which may contribute to flight efficiency under arid conditions where colonies must exploit dispersed floral resources. Conversely, *A. m. intermissa* populations generally show morphological characteristics associated with Mediterranean and semi-arid environments, where floral resources are often more spatially concentrated (Abed et al., 2021; Bakhchou et al., 2025).



Fig 1: Summary geographical distribution of races and varieties of the species *Apis mellifera*.
 According to Franck et al., 2001

However, these morphological differences should not be interpreted as completely independent adaptations. Several studies have identified intermediate phenotypes, particularly in regions where colony exchanges occur between ecological zones. This suggests that wing morphology results from a combination of genetic background, environmental influence, and historical gene flow. Therefore, morphometric variation provides valuable information about adaptation but should ideally be integrated with molecular data to improve subspecies identification and conservation decisions.

2 Physiological and behavioral adaptations

The contrasting environments occupied by *A. m. intermissa* and *A. m. sahariensis* have favored the development of different adaptive strategies. These adaptations involve physiological mechanisms, colony organization, and behavioral responses that influence survival under environmental stress.

Apis mellifera sahariensis is particularly adapted to conditions characterized by high temperatures, limited water availability, and irregular floral resources. Experimental observations indicate that Saharan bees may tolerate nutritional stress more effectively than Tellian populations, possibly through improved resource storage strategies and metabolic adjustments allowing colonies to maintain activity during unfavorable periods (Benchabane et al., 2022). The ability to efficiently regulate colony resources is particularly important in desert ecosystems, where periods of floral abundance can be short and unpredictable. Enhanced nectar and pollen storage, combined with behavioral flexibility, may contribute to colony persistence under harsh conditions.

In contrast, *A. m. intermissa* shows strong behavioral traits associated with survival in variable Mediterranean environments. Among these traits, hygienic behavior and grooming activity are particularly important because they contribute to resistance mechanisms against parasites such as *Varroa destructor* (Boecking & Ritter, 1993; Adjlane & Haddad, 2014).

The differences between the two subspecies should not be considered as a simple contrast between "more resistant" and "less resistant" populations. Instead, they represent different adaptive strategies shaped by ecological pressures. Saharan bees appear particularly specialized for resource limitation and thermal stress, whereas Tellian bees show traits associated with pathogen defense and fluctuating resource environments. Behavioral plasticity may therefore represent a key component of resilience. Foraging strategies, daily activity rhythms, and colony regulation mechanisms allow local populations to cope with environmental variability.

Nevertheless, the adaptive value of these traits requires further investigation using integrated approaches combining experimental biology, genomics, and ecological monitoring.

Pathologies, parasites, and environmental stress factors

Honey bee health is influenced by a complex interaction between parasites, pathogens, environmental conditions, and management practices. Although North African honey bees possess locally adapted traits that may increase resilience, they remain exposed to multiple interacting stressors that can compromise colony survival.

1 *Varroa destructor* and associated viral infections

The ectoparasitic mite *Varroa destructor* represents one of the most significant threats to managed honey bee colonies worldwide. The parasite weakens bees by feeding on host tissues and acts as an important vector of viral pathogens, particularly Deformed Wing Virus (DWV) (Rosenkranz et al., 2010).

In North Africa, *Varroa destructor* has become established in many apiaries, creating an important challenge for local beekeeping systems. Studies on *A. m. intermissa* indicate that this subspecies exhibits relatively developed grooming and hygienic behaviors, which may reduce mite reproduction and infestation levels compared with more susceptible populations (Boecking & Ritter, 1993).

However, these natural defense mechanisms do not provide complete protection. Under high infestation pressure, colonies may experience increased viral infection, reduced brood survival, and higher mortality risk (Claing et al., 2024). The interaction between *Varroa* and viruses illustrates an important principle in honey bee health: resistance traits alone cannot compensate for excessive environmental pressure. Effective management requires combining natural resistance, monitoring programs, and appropriate control strategies.

2 *Nosema* infections and emerging pathogens

Microsporidia of the genus *Nosema*, particularly *Nosema apis* and *Nosema ceranae*, are widespread pathogens affecting honey bee colonies. Infection can reduce lifespan, alter foraging behavior, and negatively influence colony development (Botías et al., 2013).

Studies conducted in Algerian populations have revealed complex parasite and virus patterns in *A. m. intermissa* and *A. m. sahariensis*, suggesting that disease expression depends strongly on environmental context and host-pathogen interactions (Adjlane et al., 2016).

Although some local populations may display partial tolerance, chronic infections can become problematic when combined with nutritional stress, pesticide exposure, or high colony density. Further studies are required to determine whether observed differences among subspecies reflect genetic resistance mechanisms or simply variation in environmental exposure.

3 Pesticides and combined stress effects

Agricultural intensification has increased honey bee exposure to chemical stressors, including neonicotinoid insecticides. Compounds such as thiamethoxam may induce sublethal effects affecting immunity, detoxification pathways, behavior, and metabolism (Benchaâbane et al., 2022).

Importantly, current evidence indicates that pesticide exposure rarely acts alone. The most severe impacts on colony health often result from interactions among pesticides, pathogens, and nutritional limitations (Doublet et al., 2015). For example, reduced floral diversity may decrease pollen quality and weaken immune responses, increasing susceptibility to parasites and infections (Naug, 2009; Alaux et al., 2010).

This multi-stressor perspective is particularly relevant for North African honey bees because climate change, habitat degradation, and agricultural transformation are occurring simultaneously. Even

populations with strong adaptive capacities may become vulnerable when multiple pressures exceed their physiological limits. Understanding these interactions represents a major priority for future research and for developing management strategies adapted to local conditions.

Anthropogenic and environmental threats

The conservation status of *Apis mellifera intermissa* and *Apis mellifera sahariensis* is increasingly influenced by a combination of environmental changes and human activities. While these subspecies have evolved under strong ecological constraints and display remarkable adaptive capacities, current pressures may exceed their natural resilience, particularly when several stressors act simultaneously.

1 Climate change and ecological constraints

Climate change represents one of the most important long-term challenges for honey bee populations. Increasing temperatures, prolonged drought periods, and changes in precipitation patterns can modify floral phenology, reduce nectar availability, and alter the synchronization between bee activity and plant flowering periods (Le Conte & Navajas, 2008).

These effects are particularly relevant in North Africa, where many ecosystems are already characterized by water limitation and seasonal resource availability. In Saharan and pre-Saharan regions, desertification and habitat degradation may progressively reduce the availability of suitable forage resources for *A. m. sahariensis*. Although this subspecies possesses remarkable adaptations to arid environments, rapid environmental changes may challenge its adaptive capacity. The combination of increasing temperatures, reduced floral diversity, and pathogen pressure may create conditions beyond those experienced during its evolutionary history.

Similarly, *A. m. intermissa* populations in Mediterranean and semi-arid areas may be affected by shifts in vegetation dynamics and agricultural transformation. Changes in flowering periods may reduce colony nutritional balance and influence reproductive success. Future studies should therefore focus on identifying whether local populations possess sufficient genetic variation to respond to future climatic scenarios.

2 Habitat loss, agricultural intensification, and nutritional stress

The reduction of natural habitats represents another major threat to honey bee populations. The conversion of diverse landscapes into simplified agricultural systems reduces the availability of multiple pollen and nectar sources required for colony development.

Nutritional stress has important consequences for honey bee physiology because pollen diversity directly influences immune competence, longevity, and resistance to pathogens (Naug, 2009; Alaux et al., 2010). In North Africa, these problems are intensified by recurrent droughts, land degradation, and changes in agricultural practices. Reduced floral diversity may particularly affect colonies during critical periods when alternative resources are unavailable.

Importantly, nutritional stress does not only affect colony productivity but also modifies disease susceptibility. Colonies experiencing poor nutrition may become more vulnerable to *Varroa*, viral infections, and pesticide effects. Therefore, habitat restoration and improvement of floral resources around apiaries should be considered essential components of honey bee conservation.

3 Beekeeping practices, colony movements, and genetic introgression

Modern apiculture has significantly influenced honey bee population dynamics. The movement of colonies, queen replacement, and introduction of foreign genetic material can modify the genetic structure of native populations. In North Africa, transhumance and exchange of queens between regions may increase gene flow between *A. m. intermissa* and *A. m. sahariensis*. Although gene flow can contribute to genetic diversity, uncontrolled mixing may reduce locally adapted genetic combinations.

The consequences of introgression remain insufficiently understood because available studies are based on different markers and limited geographic sampling. Therefore, further genomic investigations are required before defining precise conservation thresholds. From a health perspective, intensive colony movement also increases the risk of pathogen dissemination. Apiaries with high colony density may facilitate the spread of *Varroa*, viruses, and microsporidian infections (Seeley & Smith, 2015).

Consequently, sustainable management should balance the economic objectives of beekeeping with the preservation of native genetic resources.

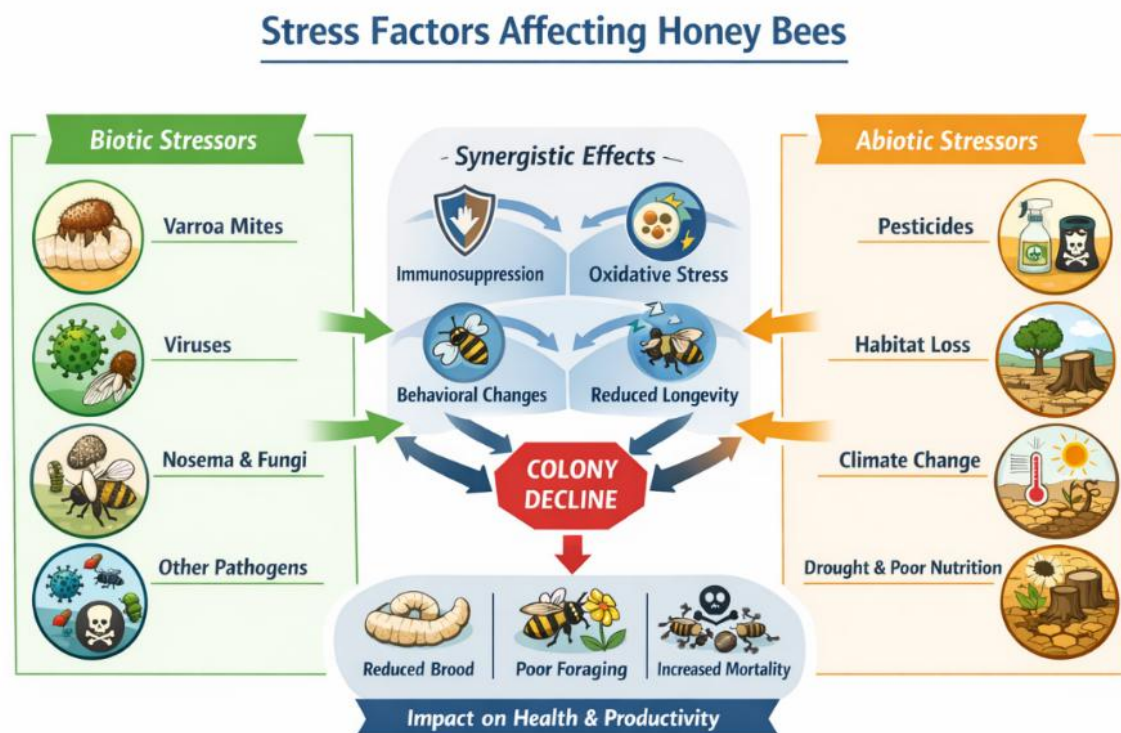


Fig. 2: Figure created by the authors using AI-assisted design tools and based on an integrative synthesis of published literature (Le Conte and Navajs, 2008; Naug, 2009; Rosenkranz et al , 2010; Goulson et al., 2015)

Conservation strategies for North African honey bees

The conservation of *A. m. intermissa* and *A. m. sahariensis* requires an integrated approach combining genetic protection, ecological management, disease control, and sustainable apicultural practices.

1 Preservation of genetic diversity and local adaptation

Genetic diversity represents the foundation of evolutionary potential and allows populations to respond to environmental changes. North African honey bees contain valuable genetic variation that should be considered a strategic biological resource. One priority action is the creation of genetic conservation zones representing different ecological regions. These areas should limit uncontrolled queen importation and encourage the maintenance of locally adapted colonies.

Such conservation areas should be supported by regular monitoring programs using complementary approaches:

- mitochondrial DNA analysis for maternal lineage identification;
- microsatellite markers for population structure studies;
- SNP-based genomic approaches for detecting adaptation-related variation;
- morphometric analyses for phenotypic monitoring.

However, conservation should not aim to completely eliminate gene flow because some genetic exchange may increase adaptive potential. The objective should instead be the preservation of regional genetic identity while maintaining sufficient diversity.

2 Breeding programs based on local adaptive traits

Selective breeding represents an important opportunity to improve colony health while conserving native genetic resources. European experiences have demonstrated that selection for hygienic behavior, grooming ability, and reduced mite reproduction can increase resistance to *Varroa destructor* (Büchler et al., 2010).

For North African honey bees, breeding programs should prioritize locally expressed traits rather than replacing native populations with imported genetic material. Important traits include:

- hygienic behavior;
- parasite tolerance;
- thermal adaptation;
- efficient resource exploitation;
- colony survival under drought conditions.

Such programs should combine scientific evaluation with beekeeper participation to ensure that selected traits correspond to both ecological adaptation and practical apicultural needs.

3 Sustainable beekeeping and policy recommendations

Long-term conservation cannot be achieved without improving management practices.

Priority actions for North African apiculture include:

1. Establishing standardized health monitoring programs for early detection of pathogens.
2. Promoting responsible control of *Varroa destructor* based on integrated pest management rather than excessive chemical treatments.
3. Improving forage availability through restoration of native flowering plants and biodiversity-friendly agricultural practices.
4. Regulating queen importation and colony movement to reduce uncontrolled genetic introgression.
5. Developing training programs to improve beekeeper awareness regarding conservation and disease prevention.

These measures should be incorporated into national agricultural and environmental policies because honey bee conservation contributes directly to crop production, biodiversity protection, and ecosystem stability.

Integrated Strategies for Honey Bee Conservation

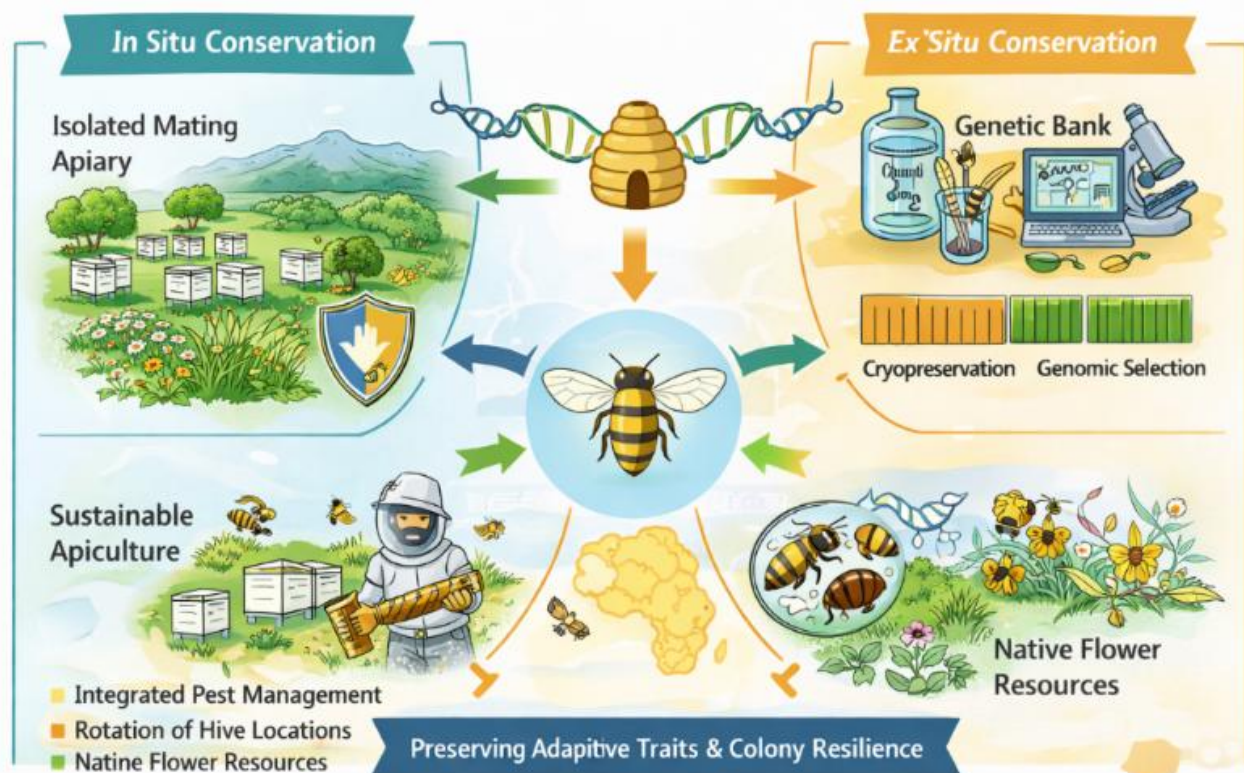


Fig 3: Integrated strategies for the conservation of the honey bee (*Apis mellifera*), developed from a synthesis of several scientific articles and created using AI-assisted design tools. (Hatjina et al. 2014 ; Abed et al., 2021; Fridi et al., 2022; Adjlane et al., 2025;)

Conclusions and future perspectives

North African honey bees, particularly *Apis mellifera intermissa* and *Apis mellifera sahariensis*, represent unique genetic resources resulting from long-term adaptation to contrasting Mediterranean and Saharan environments. Current evidence demonstrates that these subspecies possess important biological characteristics related to environmental tolerance, resource exploitation, and colony resilience. However, their future persistence is threatened by a combination of interacting factors, including parasites, pathogens, pesticide exposure, climate change, habitat degradation, and changes in beekeeping practices.

The available literature highlights the importance of considering honey bee conservation from an integrative perspective. Genetic diversity alone cannot explain population resilience; adaptive traits, ecological conditions, and management practices must also be considered.

Future research should focus on:

- genome-wide characterization of North African populations;
- identification of genes associated with thermal tolerance and disease resistance;
- long-term monitoring of genetic erosion and introgression;
- evaluation of adaptation under future climate scenarios;
- development of conservation breeding programs.

Ultimately, protecting *A. m. intermissa* and *A. m. sahariensis* requires cooperation between researchers, beekeepers, agricultural authorities, and conservation organizations. Maintaining these native subspecies represents not only the preservation of honey bee biodiversity but also an essential investment in sustainable agriculture and ecosystem resilience in North Africa.

References

- Abed, F., Bachir-Bouiadjra, B., Dahloun, L., Yakubu, A., Haddad, A., & Homrani, A. (2021). Procrustes analysis of forewing shape in two endemic honeybee subspecies *Apis mellifera intermissa* and *A. m. sahariensis* from Northwest Algeria. *Biodiversitas*, 22(1), 154–164.
- Adjlane, N., & Haddad, N. (2014). The first data on hygienic behavior of *Apis mellifera intermissa* in Algeria. *Journal of Biology and Earth Sciences*, 4(1), 1–7.
- Adjlane, N., Dainat, B., Gauthier, L., & Dietemann, V. (2016). Atypical viral and parasitic pattern in Algerian honey bee subspecies *Apis mellifera intermissa* and *Apis mellifera sahariensis*. *Apidologie*, 47(5), 631–641.
- Adjlane, N., & Haddad, N. (2018). Effect of some honeybee diseases on seasonal mortality of *Apis mellifera intermissa* in Algerian apiaries. *Proceedings of the Zoological Society*, 71, 83–87.
- Adjlane, N., Kaouche, S., Diffalah, H., Haddad, N., & Hatjina, F. (2025). Natural resistance traits in *Apis mellifera sahariensis*: A focus on hygienic behavior and seasonal performance. *Natural Resources and Sustainable Development*, 15(2), 225–232.
- Aglagane, A., Tofilski, A., Er-Rguibi, O., Laghzaoui, E. M., Kimdil, L., & El Mouden, E. H. (2022). Geographical variation of honey bee (*Apis mellifera* L. 1758) populations in south-eastern Morocco: A geometric morphometric analysis. *Insects*, 13(3), 288.
- Alaux, C., Ducloz, F., Crauser, D., & Le Conte, Y. (2010). Diet effects on honeybee immunocompetence. *Biology Letters*, 6, 562–565.
- Bakhchou, S., Aglagane, A., Tofilski, A., Mokrini, F., Er-Rguibi, O., El Mouden, E. H., Machlowska, J., Fellahi, S., & Mohssine, E. H. (2025). Morphological diversity of Moroccan honey bees (*Apis*

- mellifera* L. 1758): Insights from geometric morphometric analysis of wing venation across climatic regions. *Diversity*, 17(8), 527.
- Barour, C., Tahar, A., & Baylac, M. (2011). Forewing shape variation in Algerian honey bee populations of *Apis mellifera intermissa*: A landmark-based geometric morphometric analysis. *African Entomology*, 19(1), 11–22.
- Barour, C., & Baylac, M. (2016). Geometric morphometric discrimination of African honeybee subspecies *Apis mellifera intermissa*, *A. m. sahariensis* and *A. m. capensis*: Forewing and hindwing landmark configurations. *Journal of Hymenoptera Research*, 52, 1–15.
- Benchaaâne, S., Ayad, A. S., Loucif-Ayad, W., et al. (2022). Multibiomarker responses after exposure to a sublethal concentration of thiamethoxam in the African honeybee (*Apis mellifera intermissa*). *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, 257, 109334.
- Bendjedid, H., & Achou, M. (2014). Étude de la diversité morphométrique de deux populations d'abeilles domestiques (*Apis mellifera intermissa* et *Apis mellifera sahariensis*) du sud algérien. *Synthèse: Revue des Sciences et de la Technologie*, 28, 84–95.
- Benghalem, B., Kidoud, B., Salah, Z., Chahbar, M., & Gaouar, S. B. S. (2023). Typology and morphogeometric characterization of local bee populations *Apis mellifera intermissa* in North-West Algeria. *Genetics & Biodiversity Journal*, 7(2), 12–27.
- Berkani, M. L., Ghalem, Z., & Benyoucef, M. T. (2005). Contribution to the study of the homogeneity of the local race *Apis mellifera intermissa* in different regions of northern Algeria. *Algerian Annals of Agronomy*, 26(1), 15–32.
- Boecking, O., & Ritter, W. (1993). Grooming and removal behaviour of *Apis mellifera intermissa* in Tunisia against *Varroa jacobsoni*. *Journal of Apicultural Research*, 32(3–4), 127–134.
- Botías, C., Martín-Hernández, R., Barrios, L., Meana, A., & Higes, M. (2013). *Nosema* spp. infection and its negative effects on honey bees (*Apis mellifera iberiensis*) at colony level. *Veterinary Research*, 44, 25.
- Büchler, R., Berg, S., & Le Conte, Y. (2010). Breeding for resistance to *Varroa destructor* in Europe. *Apidologie*, 41, 393–408.
- Cameron, J. J., & Ellis, J. D. (2021). Integrated pest management control of *Varroa destructor*, the most damaging pest of *Apis mellifera* colonies. *Journal of Insect Science*, 21(5), 6.
- Claing, G., Dubreuil, P., Bernier, M., Ferland, J., L'Homme, Y., Rodriguez, E., & Arsenault, J. (2024). *Varroa destructor* and deformed wing virus interaction increases incidence of winter mortality in honey bee colonies. *Canadian Journal of Veterinary Research*, 88(3), 69–76.
- Cobey, S. W., Sheppard, W. S., & Tarpy, D. R. (2013). Status of breeding practices and genetic diversity in honey bees (*Apis mellifera*). *Journal of Apicultural Research*, 52(1), 1–12.
- Doublet, V., Labarussias, M., de Miranda, J. R., Moritz, R. F. A., & Paxton, R. J. (2015). Bees under stress: Interactions between pathogens, pesticides and nutrition. *Trends in Parasitology*, 31(12), 614–624.

- FAO. (2019). *Good beekeeping practices for sustainable apiculture*. FAO Animal Production and Health Guidelines. Rome: Food and Agriculture Organization.
- Franck, P., Garnery, L., Solignac, M., & Cornuet, J. M. (2000). Molecular confirmation of a fourth lineage in honeybees. *Journal of Heredity*, 91, 162–168.
- Franck, P., Garnery, L., Loiseau, A., et al. (2001). Genetic diversity of the honeybee in Africa: Microsatellite and mitochondrial data. *Heredity*, 86, 420–430.
- Fridi, R., Tabet Aoul, N., Catays, G., et al. (2022). Genetic diversity and population genetic structure analysis of *Apis mellifera* subspecies in Algeria and Europe based on the complementary sex determiner gene. *Apidologie*, 53, 4.
- Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, 347(6229), 1255957.
- Harbo, J. R. (1986). Preservation of honey bee semen. *Journal of Apicultural Research*, 25, 245–247.
- Hatjina, F., et al. (2014). Conserving honey bee diversity: The importance of local adaptation. *Journal of Apicultural Research*, 53(2), 245–252.
- Haddad, N. J., Loucif-Ayad, W., Adjlane, N., et al. (2015). Draft genome sequence of the Algerian bee *Apis mellifera intermissa*. *Genomics Data*, 4, 24–25.
- Klein, A. M., et al. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B*, 274, 303–313.
- Le Conte, Y., & Navajas, M. (2008). Climate change: Impact on honey bee populations and diseases. *Revue Scientifique et Technique (OIE)*, 27(2), 485–497.
- Meixner, M. D., Costa, C., Kryger, P., Hatjina, F., Bouga, M., Ivanova, E., & Büchler, R. (2010). Conservation of diversity in *Apis mellifera*. *Journal of Apicultural Research*, 49(1), 85–92.
- Naug, D. (2009). Nutritional stress due to habitat loss may explain recent honeybee colony collapses. *Biological Conservation*, 142, 2369–2372.
- Rosenkranz, P., Aumeier, P., & Ziegelmann, B. (2010). Biology and control of *Varroa destructor*. *Journal of Invertebrate Pathology*, 103(S1), S96–S119.
- Seeley, T. D., & Smith, M. L. (2015). Crowding honeybee colonies in apiaries can increase disease transmission. *PLoS ONE*, 10(5), e0127249.
- Yordanova, M., Evison, S. E. F., Gill, R. J., & Graystock, P. (2022). The threat of pesticide and disease co-exposure to managed and wild bee larvae. *International Journal for Parasitology: Parasites and Wildlife*, 17, 319–326.