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Relationship Between Genetic Diversity and Habitat Preference: A Case Study of Butterflies (*Rhopalocera*)

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Abstract This study analyzes the relationship between genetic diversity and habitat preference in butterflies (*Rhopalocera*). It systematically introduces the diversity of butterflies, including their extensive classification and ecological distribution, as well as their life cycle and behavioral characteristics. The concepts of genetic diversity and habitat preference are further explored, emphasizing their importance for species survival and adaptability. By reviewing existing research, including the application of genomic technologies in butterfly studies and the factors influencing butterfly habitat preferences, the study delves into the association between butterfly genetic diversity and habitat preference, highlighting differences among various butterfly species and possible mechanisms. This research provides scientific evidence and future research directions for understanding the relationship between butterfly ecology and genetics.

Keywords Butterflies (*Rhopalocera*); Genetic diversity; Habitat preference; Ecology; Conservation research

1 Introduction

The butterfly (*Rhopalocera*) is one of the fascinating representatives of biodiversity in the insect kingdom. They are famous for their magnificent wings, colorful colors, and charming flight postures, attracting the interest of countless biologists and nature enthusiasts. However, the charm of butterflies is not limited to their beauty. These organisms are also important ecosystem members and play a crucial role in plant pollination, ecological chain balance, and ecosystem stability (Feng et al., 2021).

With the increasingly severe disturbance and habitat loss of global ecosystems, there is an urgent need to protect and conserve sensitive organisms such as butterflies. Understanding the relationship between genetic diversity within butterfly populations and their preferences for different habitats has become crucial (Sun et al., 2020). Genetic diversity is often considered a determining factor for population adaptability and survival, while habitat preference involves the environment in which butterflies choose to live and reproduce. This not only helps to reveal the adaptability and survival mechanisms of butterflies, but also provides scientific basis for formulating protection strategies to ensure their survival.

This study will delve into the relationship between genetic diversity and habitat preferences, summarize existing research results, explore the differences between different butterfly species, and propose future research directions. By conducting in-depth research on the relationship between butterfly genetic diversity and habitat preferences, the aim is to provide scientific basis for better protecting this fascinating biological population and maintaining the stability and diversity of ecosystems.

2 Diversity of Butterflies

2.1 Classification and ecological distribution of butterflies

Butterfly is a member of the Lepidoptera order in the Insecta phylum, which is a class of insects with wings and scales covering them. This major category includes nearly 18 000 different butterfly species, which are further subdivided into different families, genera, and species based on their external morphology and genetic characteristics (Xie et al., 2018). These different taxonomic units have their own unique characteristics, such as wing shape, body color, and lifestyle habits, which enable them to adapt to different ecological environments.

The ecological distribution of butterflies is extensive and widespread worldwide, with the presence of butterflies in almost every ecosystem, from polar regions to tropical rainforests (Delpon et al., 2019). They can be found in continents, islands, and various habitats, including forests, grasslands, wetlands, deserts, etc. The widespread distribution of butterflies provides multiple ecological backgrounds for studying the relationship between genetic diversity and habitat preferences.

2.2 The life cycle and behavioral characteristics of butterflies

The life cycle of butterflies undergoes four main stages: egg, larva, pupa, and adult (Lindestad et al., 2022). Eggs are the earliest stage of life, usually laid by adults and attached to the host plant. Larvae is the herbivorous stage of butterflies, which accumulate energy by eating leaves and gradually grow after several molts. Then, the larvae enter the pupal stage and undergo comprehensive physical changes within the pupa, ultimately becoming winged adults. Adults are the stage of reproduction and flight, playing an important role in finding food, partners, and suitable habitats.

The behavioral characteristics of butterflies play an important role in their lifecycle and are closely related to habitat preferences (Attiwilli et al., 2022). Different types of butterflies have different flying habits, some are strong flyers, and some are more inclined to hover or glide. These flight habits are related to their distribution in their habitats and their strategies for finding food. Butterflies feed on pollen, nectar, fruits, or decaying matter, and their feeding habits have a significant impact on plant pollination and the health of plant ecosystems. The breeding behavior of butterflies includes finding suitable host plants, laying eggs, and caring for larvae. These behaviors are related to the availability of habitats and plant resources, and are crucial for the success of population reproduction.

3 Study on the Habitat Preference of Butterflies

3.1 Habitat requirements and selection of butterflies

Butterflies are unique creatures in the insect kingdom, and their habitat needs and choices play a crucial role in their survival, reproduction, and adaptability. There are significant differences in the habitat needs of different types of butterflies, including factors such as plant species, climate conditions, and altitude (Shang et al., 2020). The life cycle of butterflies is complex, from eggs, larvae, pupae to adults, each stage has different needs for specific habitat conditions.

Vanessa indica Herbst is a famous butterfly whose habitat needs involve specific host plants, mainly naturally released milkweed. These plants are the only food source for the larvae of the red butterfly, so the red butterfly is very sensitive to the availability of these plants. They also undergo large-scale seasonal migration on the North American continent, requiring suitable climatic conditions to reproduce and survive the winter.

Butterflies usually prioritize host plants that are suitable for their larvae in habitat selection. These plants not only provide food, but also provide spawning sites for their eggs (Li et al., 2019). Butterflies also have certain preferences for sunlight, temperature, and humidity. Some butterflies tend to inhabit open grasslands, while others may be more adapted to the environment within the forest.

The *Pontia daplidice* Linnaeus is a butterfly that prefers open grasslands, and its habitat selection typically involves grasslands and herbaceous plants. They have a high preference for sunny areas, which makes them more active in bright weather. The larvae of the cloud spotted butterfly also rely heavily on certain leguminous plants as host plants, which further affects their habitat selection.

Habitat selection not only depends on the biological characteristics of individual butterflies, but also is influenced by competition and predator pressure. In situations where resources are limited, butterflies may need to compete with other species to obtain sufficient food and habitat. In addition, the availability and stability of habitats can also affect the selection of butterflies (Shang et al., 2020). Some butterflies may prefer stable habitats, while others may be more adaptable to seasonal changes.

Purple crow butterflies are a type of butterfly found in forests, and their habitat choices typically include tree canopy and forest areas. They prefer a humid environment and usually move around trees. The larvae of the purple spotted butterfly host trees such as poplar and elm, which also affects their habitat selection within the forest.

3.2 Impact of habitat destruction and changes

The habitat of butterflies is facing increasingly severe destruction and change, which has a profound impact on their survival and ecosystem functions. Habitat destruction includes human activities such as deforestation, urbanization, agricultural expansion, and land development, as well as natural factors such as fires and climate change. These factors have led to fragmentation and loss of habitats, limiting the activity and reproduction of butterflies.

The destruction and change of habitats have had multiple impacts on butterflies. Habel et al. (2022) found strong temporal trends in the relative species richness pS and relative abundance pA of most butterfly guilds (Figure 1), for six of the 12 traits studied, they detected breakpoints in the 1960th and 1970th, indicating severe prior changes in important habitat conditions. The loss of habitat reduces the living space of butterflies, making them more vulnerable to predators. Habitat destruction may lead to a decrease in host plants, which will directly affect the food supply for butterfly larvae. Habitat changes may lead to unstable climate conditions, affecting the breeding and migration patterns of butterflies. These factors work together and have a negative impact on the population size and diversity of butterflies.

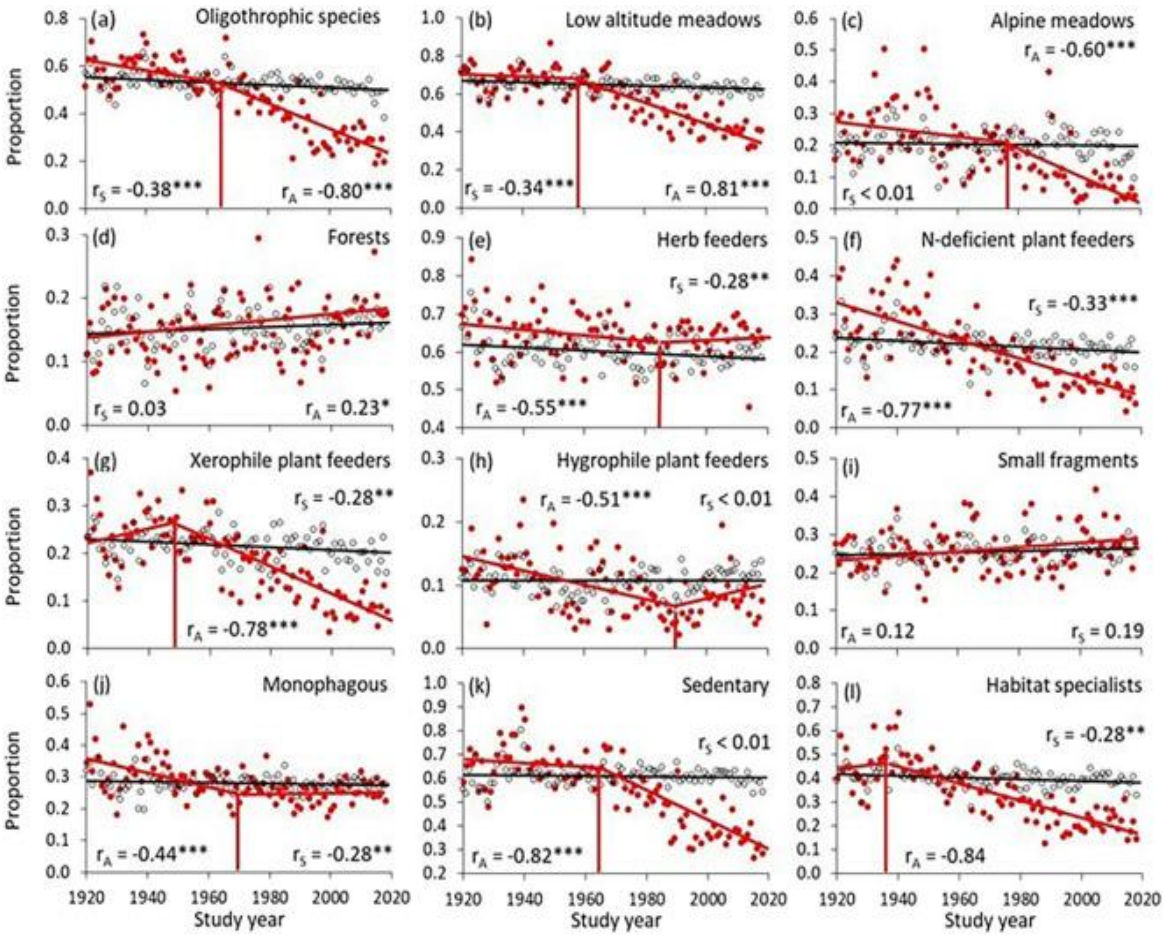

Figure 1 Temporal trends in the proportions of species belonging to 12 different ecological guilds (Adopted from Habel et al., 2022)

Image caption: Open black dots: proportions of species (coefficient of correlation rS), red dots: relative abundances (coefficient of correlation rA); Significant breakpoints of rA in a):1965, b) 1959, c) 1977, d) lack, e) 1985, f) lack, g) 1948, h) 1990, i) lack, j) 1970, k) 1964, l) 1937; Parametric significances of linear OLS regressions: * P < 0.05, ** P < 0.01, ***: P < 0.001 (Adopted from Habel et al., 2022)

Habitat destruction may also lead to a decrease in the genetic diversity of butterflies (Joanna and Nowicki, 2023). Due to habitat destruction and segregation, communication between butterfly populations decreases, which may lead to genetic differentiation between populations and reduce genetic diversity. Genetic diversity is crucial for the adaptability of species, as it can make it easier for them to adapt to environmental changes and new pressures.

Monarch butterfly is a famous migratory butterfly, with its migration route spanning North America. Habitat destruction includes winter habitat deforestation in Mexico, as well as urbanization and agricultural expansion of grasslands and wildflower grasslands in the United States and Canada. This has led to habitat loss and reduced food supply during migration, posing a threat to their migration and survival.

The *Ornithoptera urvillianus* is widely distributed in Asia and Oceania, but faces the threat of habitat destruction. Deforestation, land development, and urban expansion have led to the loss of habitat for the blue bird winged butterfly, leading to a decline in their population and posing a risk of endangerment.

4 The Relationship between Genetic Diversity and Habitat Preferences

4.1 Application of genomics technology in butterfly research

In recent years, the development of high-throughput DNA sequencing technology has changed the way gene diversity research is conducted. By using DNA sequencing technology, researchers can analyze the DNA sequence in the butterfly genome to reveal the differences and variations between different genes. This helps to understand the genetic diversity of butterflies, including single nucleotide polymorphisms (SNPs), among others.

Transcriptomics technology allows scientists to study which genes in the butterfly genome are expressed under specific conditions (Xiao, 2022). This is crucial for understanding the adaptability and survival strategies of butterflies in different habitats. By analyzing the transcriptome of butterflies, researchers can identify gene expression differences related to habitat preferences.

By studying the nucleotide sequences of butterfly reproductive cells, scientists can understand the situation of gene flow and genetic communication. This helps to determine the degree of genetic connection between different butterfly populations and whether there is genetic segregation.

4.2 Summary of existing research results

Previous studies have provided important insights into the relationship between butterfly genetic diversity and habitat preferences. These studies indicate a close relationship between genetic diversity and butterfly habitat preferences (Sun et al., 2020). Research has found that in butterfly populations with high genetic diversity, individuals have stronger adaptability to different habitat types. This indicates that genetic diversity helps increase the survival opportunities of butterfly populations, enabling them to adapt to different habitat conditions.

There are inter species differences between the habitat preferences and genetic diversity of butterfly species. Some butterfly species may be more sensitive to habitat changes, while others are more adaptable. This difference may be related to the life history, behavior, and ecological needs of different species.

Research has also shown that habitat changes and destruction have a negative impact on the genetic diversity of butterflies (Peng et al., 2023). Habitat destruction has led to a decrease in the number of species, thereby reducing the size of the gene pool and reducing genetic diversity. This makes butterflies more vulnerable and difficult to adapt to changes in their habitats. Therefore, protecting the habitat of butterflies is crucial for maintaining their genetic diversity.

The different populations of *Parthenos sylvia gambrisius* exhibit different levels of genetic diversity in their habitat diversity. This reflects the close relationship between genetic diversity and habitat changes. Endangered butterfly species such as the three tailed brown butterfly (*Bhutanitis thaidina*) typically have low genetic diversity, making them more vulnerable to threats such as habitat destruction and climate change. The protection of these species has become particularly urgent as they may become more vulnerable to any further damage to their habitats.

4.3 Differences between different butterfly species

There are significant differences in habitat preferences and genetic diversity among different butterfly species. These differences can be attributed to various factors, including the species' life history, food needs, behavior, and geographical distribution. Behavioural categorization of García-Berro et al. (2023) resulted in 16 species scored as migratory (17.64%), 69 as sedentary (65.66%) and 13 as dispersive (12.74%) (Figure 2). Some butterfly species have a long life history, such as long-distance flight and multi generational characteristics. These species may be more adaptable and able to find food and spawning grounds in different habitats. Other species have a shorter life history and are more sensitive to specific habitat conditions.

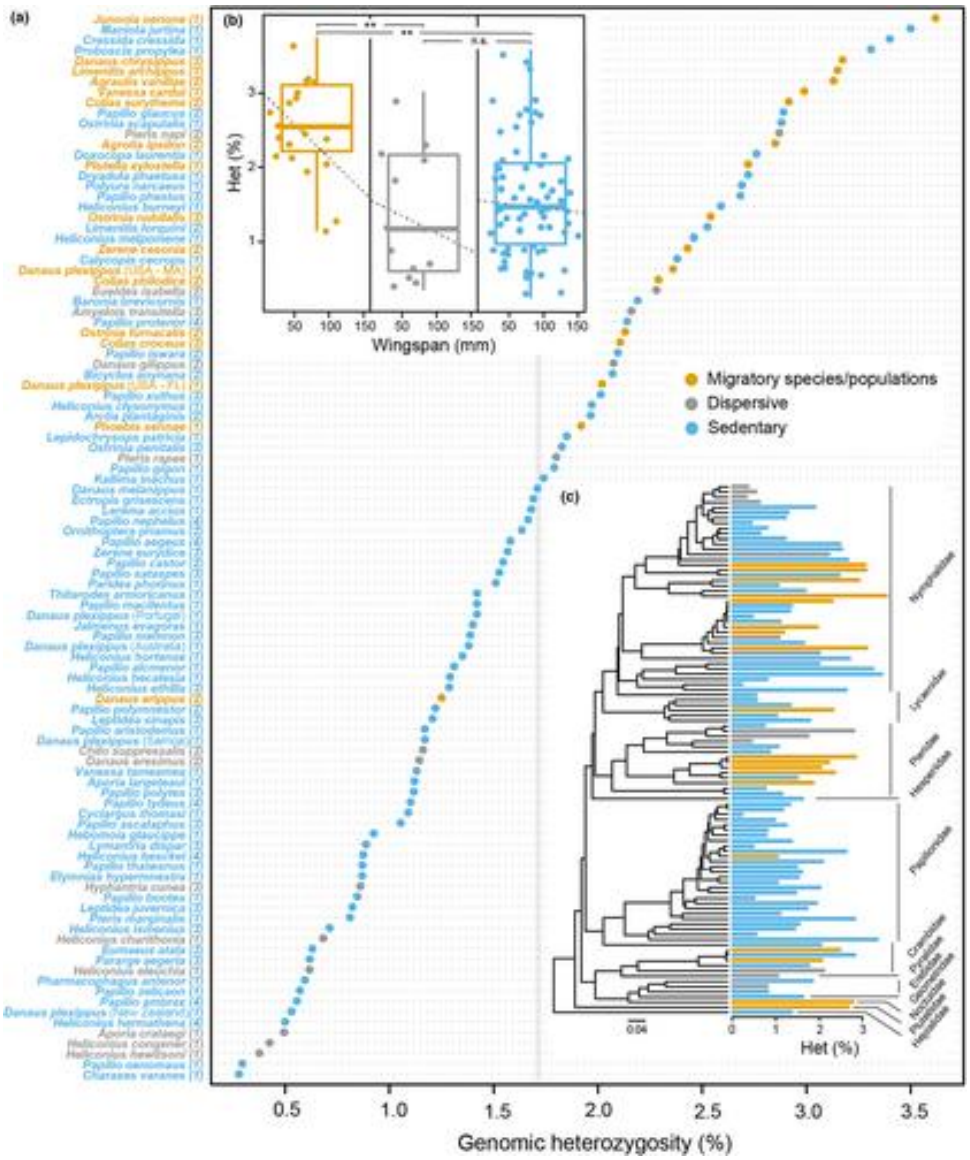

Figure 2 Behavioural categorization of 97 lepidopteran species (Adapted from García-Berro et al., 2023)

Image caption: (a) Genomic heterozygosity for 185 individuals belonging to 97 lepidopteran species calculated from short read Illumina reads using genomescope version 1.0; Average estimates for species with several specimens are shown, with the exception of Danaus plexippus, for which migratory and nonmigratory populations are illustrated; Numbers next to species names denote the number of individuals used for heterozygosity inference; The grey line indicates the average value for all analysed species; Species were classified as sedentary (in blue), migratory (in orange) and dispersive (in grey); (b) a pGLS analysis was used to test for significant deviation in heterozygosity between groups, accounting for wing size as proxy for body size (*p < .05, **p < .01; ***p < .001); (c) Phylogenetic diversity of the sampled species; Bars next to tips show average heterozygosity estimates (Adopted from García-Berro et al., 2023)

The larvae of butterflies usually have different food needs for different host plants. Some species have a strong dependence on specific plants, which may limit their ability to find suitable habitats. Other species are more selective and can utilize a variety of different plants. The geographical distribution of different butterfly species also affects their habitat preferences and genetic diversity. Some species are widely distributed and can adapt to multiple habitat types, while others may only appear in specific regions.

These differences emphasize the need to consider species diversity and complexity when studying the relationship between genetic diversity and habitat preferences.

The tiger spotted butterfly (*Danaus generia* (Cramer)) has a relatively long life history and can fly over long distances. They can find suitable food and spawning grounds in different types of habitats, including forests, fields, and urban environments. This adaptability gives them high flexibility in terms of genetic diversity.

In contrast, the *Pieris rapae* is a smaller butterfly with a specific demand for host plants. Their larvae mainly feed on cruciferous plants, so their habitat selection is relatively limited. This leads to differences between their genetic diversity and habitat preferences.

4.4 Possible mechanisms and explanations

In order to gain a deeper understanding of the relationship between butterfly genetic diversity and habitat preferences, researchers have proposed some possible mechanisms and explanations.

Genetic diversity can provide butterfly populations with more adaptive gene choices. *Nymphalidae*, which may reproduce under different habitat conditions. Genetic diversity provides these butterflies with more genetic variations, enabling some individuals to perform better under specific habitat conditions, such as better resistance, more adaptive life history strategies, or more appropriate behavioral adaptations. This makes it easier for butterfly populations to adapt to environmental pressures in different habitats.

Habitat changes and destruction may lead to a decrease in the number of species, thereby increasing the chances of genetic drift. The *Danaus plexippus* species have decreased due to environmental degradation and human agricultural activities. This may lead to a decrease in genetic diversity, as smaller populations are more susceptible to genetic drift. This makes butterflies more susceptible to habitat changes as they lack sufficient genetic diversity to adapt to new conditions.

The gene flow between different butterfly individuals may also affect the relationship between gene diversity and habitat preferences. The subspecies of the Chinese tiger butterfly (*Luehdorfia chinensis*) that lives in mountains and plains. If these two subspecies can communicate genes, genetic diversity may be maintained at a high level. This gene flow can help butterfly populations maintain sufficient genetic diversity to adapt to different habitat types.

The behavioral characteristics and choices of butterflies may also affect their habitat preferences. Some butterflies may prefer to choose habitats that match their genetic diversity to improve their success rate in reproduction and survival. The *Papilio memnon* may choose habitats that provide more host plant species during the breeding season, as this can improve the survival rate of its larvae, which may be related to its genetic diversity.

5 Concluding Remarks

Through in-depth research, some important conclusions and insights have been drawn. The butterfly (*Rhopalocera*) is an insect species with extensive ecological and taxonomic diversity. The life cycle and behavioral characteristics of butterflies have a significant impact on their habitat selection and adaptation. Genetic diversity plays a crucial role in the survival and adaptability of butterflies, which is closely related to their success in survival in various habitats. The differences in genetic diversity and habitat preferences among different butterfly species provide a deeper understanding.

The relationship between genetic diversity and habitat preferences is crucial for the survival and reproduction of butterflies. High genetic diversity can enhance the adaptability of butterfly species, making them better able to cope with habitat changes and environmental pressures. Genetic diversity can also promote the health and stability of populations, reduce the risk of genetic drift, and thus help maintain species diversity. The habitat preferences of butterflies directly affect their survival and reproductive success. Understanding the habitat selection and needs of different butterfly species can help formulate effective protection measures and protect ecosystems.

Although some progress has been made, there are still many open-ended issues that need further research. Further research is needed on the impact of different habitat types on the genetic diversity and habitat preferences of butterflies. This will help to better understand the long-term impact of habitat changes on butterfly species. More research is needed to reveal potential genetic mechanisms and explain why different butterfly species differ in genetic diversity and habitat preferences. This will help to gain a deeper understanding of the ecological genetics of butterflies.

Subsequent research requires more extensive surveys and monitoring efforts to understand the dynamic changes in butterfly populations and habitat conditions. This will provide data support for developing more effective protection plans. The advancement of interdisciplinary research is crucial in integrating knowledge of ecology, genetics, biogeography, and conservation biology, in order to gain a more comprehensive understanding of the relationship between genetic diversity and habitat preferences.

Future research should also focus on improving and innovating research methods to better study the relationship between butterfly genetic diversity and habitat preference. With the continuous development of molecular biology and genomics technology, butterfly genomes can be analyzed in greater depth to reveal specific genes related to habitat preferences. At the same time, adopting more accurate habitat survey and monitoring methods to obtain more accurate data can help to gain a more detailed understanding of butterfly habitat preferences.

Cross disciplinary cooperation and data sharing are also crucial. By integrating professional knowledge and data from different fields, the relationship between genetic diversity and habitat preferences can be more comprehensively studied, thereby better protecting this important ecological resource.

In summary, the relationship between butterfly genetic diversity and habitat preferences is a complex and fascinating field that requires continuous research and collaboration to better understand this critical ecological phenomenon. Through in-depth research and innovative methods, the aim is to provide scientific basis for the protection of butterfly species and the sustainability of ecosystems.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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