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研究課題名（和文）Elucidating the coevolutionary relationship between sociality and social immunity: a study using facultatively social bees

研究課題名（英文）Elucidating the coevolutionary relationship between sociality and social immunity: a study using facultatively social bees

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研究成果の概要（和文）：2023/2024年度の主な目標は、実験のセットアップを確定し、フィールドサイトを確立することであった。これには必要な機器を購入し、プロジェクトに必要なプロトコル、材料、条件を入念に設計・準備することが含まれる。日本の研究者と連絡を取り、日本全国に協力ネットワークを構築し、次年度のミツバチの採集とフィールドワーク場所の確立に協力することにした。沖縄の渡嘉敷で予備的なフィールドワークを実施し、実験手法の初期テストと検証に必要なハチの標本を収集した。

研究成果の学術的意義や社会的意義

We provided the first insights into how immune responsiveness varies intra-specifically in different social and environmental contexts. This information provides unique insights into the evolution of social immunity.

研究成果の概要（英文）：For the 2023/2024 fiscal year, the primary goal was to finalize the experimental setup and establish field sites. This involved purchasing the required equipment and carefully designing and preparing the protocol, materials, and conditions required for the project. We contacted Japanese researchers to build collaborative networks across Japan to help with the collection of bees and establish fieldwork sites for the upcoming year. We conducted preliminary fieldwork in Tokashiki, Okinawa to collect bee specimens which were necessary for initially testing and validating the experimental approach.

研究分野：Behavioural Ecology

キーワード：climate change bees thermal tolerance latitudinal gradient

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様式 C - 19、F - 19 - 1 (共通)

1 . 研究開始当初の背景

1. Initial background to the study

The coevolutionary struggle between hosts and their parasites and pathogens (hereafter P&P) is one of the most fundamental forces driving natural selection, and thought to underlie major evolutionary transitions such as the evolution of sexual reproduction. Social organisms face higher risks from P&P through increased likelihood of discovery and transmission, facilitated by high genetic relatedness. However, these costs can be offset by benefits accrued through 'social immunity', which comprises a diverse array of anti-P&P activities at the group level and is found in a broad range of organisms from mammals to bacteria.

As both social and individual immune responses carry a cost, we can expect a trade-off to exist between investment in individual and social immunity (Immunity Trade Off (ITO) hypothesis). Data from cross-taxonomic comparisons support this idea: highly social bees possess many fewer genes for personal immunity than non-social bees, and expression of immune genes is higher in solitary than group-living locusts. This has led some to suggest that the evolution of social immunity may be closely associated with the evolution and elaboration of animal societies. However, studies to date have focused only on comparisons between highly eusocial organisms such as honeybees and solitary organisms. To further elucidate this relationship, we require information on social immunity in organisms with more rudimentary societies, and within species exhibiting multiple social forms. This study will address this knowledge gap by investigating the relationship between immunity and sociality using a parallel, intra-specific approach which focuses on facultatively social bees.

2 . 研究の目的

2. objectives of the study

The major evolutionary transition to group living has occurred repeatedly, and this is usually explained by social benefits such as cooperative defence and specialization. However, less attention has been given to how societies mitigate the costs of group living such as increased risk from P&P. To advance our understanding of the evolution of group living, we must thus first elucidate the mechanisms which limit the risk of P&P in group living individuals.

This study focussed on facultatively social bees, and aimed to determine whether investment in immunity differs between individuals in social and solitary contexts. These animals live both alone and in small colonies, allowing us to contrast immunity across this transition, where investment in social versus individual immunity is likely to exhibit the greatest variation. From the ITO hypothesis (above), we expect to observe a decrease in individual immune investment with increasing colony size, as benefits accrue from social immunity. Alternatively, the Density dependent prophylaxis (DDP) hypothesis, states that social individuals should have higher individual immunity because of the higher risk of P&P transmission in societies. If the ITO hypothesis is correct, we can predict that individuals in social colonies will exhibit: i) lower latent individual immunity, ii) weaker individual immune responses, and iii) more social immune behaviours, with the opposite supporting the DDP hypothesis.

We used two species of facultatively social bee, and compared social and solitary colonies within each species, avoiding potential confounding variables of inter-specific approaches. As social immunity is the combined effect of a diverse range of behavioural processes, its direct effects are difficult to quantify. Individual immunity, on the other hand, has been broadly studied in insects and can be quantified using a variety of different approaches. We thus focussed on a comparative assessment of individual immunity in bees in social and solitary contexts.

3 . 研究の方法

3. research methods

We will use two species of facultatively social bees with rudimentary societies: *Lasioglossum baleicum* and *Ceratina okinawana*. We compared immune capacity in individuals from solitary and social nests using colonies collected during life-cycle phases in which both social and solitary colonies are present.

Immunity was assessed using two methods. Firstly, we developed a new immune assay to quantify the capacity for individuals to suppress bacterial growth, allowing direct, laboratory assessment of immune efficacy at the individual level. This method relies on optical assessment of bacterial growth of genetically modified bacteria in haemolymph (insect "blood") extracted from bees. Haemolymph suppresses bacterial growth, allows us to assess immune efficacy by comparing with control samples. Secondly, we compared gene expression of immune responsiveness, allowing us to elucidate the genes responsible in immune responses in difference contexts. Specifically, we tested whether social context influenced gene expression patterns in response to an immune challenge.

Social status (solitary/social) was determined from demographic information supported by data from dissections of adults, allowing us to test social and solitary contexts.

4 . 研究成果

4. Research results

The development of the new immune assay allowed accurate quantification of individual immune efficacy. This method was used successfully to demonstrate that while immune efficacy of individual immunity was higher in social than solitary colonies of *C. okinawana*, this was largely the influence of group size. Thus, individuals increase their immune investment in larger size groups, likely because of the increased threat of disease transmission. This study was published in *Biology Letters*. We were also able to show that there were differences in individual immune expression between urban and rural bee colonies (manuscript currently in prep.).

Our analysis of gene expression in *L. baleicum* showed that gene expression patterns differed in social and solitary bees, and that gene expression was highly responsive to social context. Bees thus responded more similarly to immune threat based on their current, rather than long term social context. This indicates that immune responsiveness is strongly influenced by, and highly adaptable to, social context. This manuscript is currently in preparation.

This research was thus able to i) develop a novel immune assay which is broadly suitable for future immune testing, ii) demonstrate the influence of social context on immune efficacy in two different species of bee, iii) demonstrate the importance of environmental context in bee immune expression, iv) elucidate the genetic basis of adaptive immune responsiveness.

5. 主な発表論文等

〔雑誌論文〕 計1件（うち査読付論文 1件/うち国際共著 1件/うちオープンアクセス 0件）

1. 著者名 Nguyen Thi Thu Ha, Asano Tsukani, Cronin Adam L.	4. 巻 19
2. 論文標題 Group size rather than social status influences personal immune efficacy in a socially polymorphic bee	5. 発行年 2023年
3. 雑誌名 Biology Letters	6. 最初と最後の頁 20230149
掲載論文のDOI（デジタルオブジェクト識別子） 10.1098/rsbl.2023.0149	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕 計2件（うち招待講演 0件/うち国際学会 1件）

1. 発表者名 Thi Thu Ha Nguyen, Tsunaki Asano and Adam L Cronin
2. 発表標題 Group size influences individual immune efficacy in a socially polymorphic bee.
3. 学会等名 41st Conference of the Japan Ethological Society, Fukuoka, Japan, November 22-24, 2022.
4. 発表年 2022年

1. 発表者名 Ha Nguyen, Tsunaki Asano, Adam L. Cronin
2. 発表標題 The influence of social context on personal immunity.
3. 学会等名 International Society for Behavioural Ecology Congress 2022, Sweden, July 28 - August 2, 2022. (国際学会)
4. 発表年 2022年

〔図書〕 計0件

〔産業財産権〕

〔その他〕

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6. 研究組織

氏名 (ローマ字氏名) (研究者番号)	所属研究機関・部局・職 (機関番号)	備考
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7. 科研費を使用して開催した国際研究集会

〔国際研究集会〕 計0件

8 . 本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関
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