BIO Web of Conferences **142**, 02002 (2024) https://doi.org/10.1051/bioconf/202414202002
ISAEB 2024

Ant's Social Division of Labor and Its Influencing Factors

Jinwen Fu*

Jinhua City Junhua International School, Jinhua 321000, China

Abstract. As a higher social insect, ants have a clear hierarchy within them. According to the different divisions of labor, ant groups mainly include worker ants, soldier ants, male ants, and queen ants. In this paper, the social division of labor and its influencing factors on ants are studied in-depth. The main characteristics, physiological functions and behaviors of different grades of ants are explained, and the strong correlation between them and the social division of labor of ants is discussed from the aspects of gene differential expression, epigenetic regulation and brain specificity. From the behavioral level to the molecular level, this paper reveals the social division of labor and influencing factors of ants and lays an essential foundation for the study of ants' social behavior.

1 Introduction

Ants are a kind of higher social insects, which live based on groups, have a clear division of labor and cooperation, and have the differentiation of reproductive and non-reproductive individuals. There is a clear hierarchy and individual division of labor within the ant colony, which is mainly divided into worker ants, soldier ants, male ants and queen ants. The worker ants are responsible for digging nests and caring for all individuals in the ant colony; the soldier ants are responsible for defending the ant nest; queens and males are responsible for the reproduction of offspring [1].

Worker ants develop from fertilized eggs and are smaller than queens and males, especially in the chest and abdomen, the gonads are degraded, and no wings. Workers have different individual divisions, including taking care of the queen in the ant nest, going out for food, defending the ant nest, and exercising the function of the storage tank. The worker ants who go out to collect food, collect nectar from flowers and store it in the digestive tract of the ants. At the same time, the water is absorbed by the ants, and finally fills the entire digestive tract of the ants to form a 'honeypot'; such ants lose their ability to act as a food source, feeding the nectar in the digestive tract back to other ants. Living inside the nest, by sacrificing their own freedom, protects the interests of the entire colony. Worker ants can be divided into several subclasses according to their size. Large workers usually defend the larvae and the queen in the nest. Tiny workers are mostly responsible for going out to forage, so they are better able to cope with environmental stress. The worker ant is the largest type in the group, which plays an essential role in the ant colony and is responsible for the operation of the entire ant colony.

There is also a type of ants called soldier ants. Soldiers do not dig nests and do not take care of queens and juvenile ants, but they can defend the nest and prevent the rest of the ants from occupying the nest. Certain types of soldier ants also have the ability to cut seeds, and after the seeds are brought back to the nest by different types of worker ants, the soldier ants cut the seeds inside the nest for consumption by the colony. Among some species of ants, the soldier ants are also served by the worker ants.

Male ants develop from the unfertilized eggs laid by the queen. The male ant has wings and is smaller than the large worker ant. The head is the smallest in the entire ant colony, but it has developed a vision to facilitate the search for queens to mate. The only role of male ants in the ant colony is to mate with the queen. After performing the function of mating, the male ants die. Therefore, after the male ants develop from larvae to adults and perform mating, they disappear in the group.

The queen ant is a female ant developed from fertilized eggs with developed gonads and reproductive ability. The body size is typically the largest in the ant colony. After the successful emergence of the queen ant, it has wings, and after mating with the male ant, the wings will fall off. The queen is responsible for oviposition and feeding juvenile ants in the ant colony. There may be one or more queens in the ant colony, which is the highest group in the ant colony.

2 The main regulatory mechanism for the emergence of hierarchical differentiation in ants

Both queen and worker ants have diploid genomes, but their morphology, physiological functions, and behaviors are extremely different, ultimately resulting in differences in social hierarchies. Some researchers have

* Corresponding author: Kang1972@qq.com

made a detailed analysis of the causes of the differences in the social division of labor of ants. The influencing factors mainly include epigenetic regulation, gene expression differences, brain specificity, and so on.

2.1 Epigenetic regulation

The caste differentiation and development of ants are closely related to epigenetic regulation, especially affected by DNA methylation. Some studies have examined DNA methylation in Florida bowback ants and Indian jumping ants and found that social class differentiation and developmental changes in ants are regulated by methylation, providing an essential molecular biology and genetics basis [2]. Specifically, DNA methylation exists not only in CpG sites, but also in non-CpG sites, and mostly occurs in the exon regions of transcriptionally active genes. Methylation of non-CpG sites may mediate essential biological functions in ants; methylation of transcriptionally active genes normally occurs in the second exon region of the gene, affecting variable shearing, exon jumping, and thus the process of gene expression.

DNA methylation acts on various genes and has an influential impact on the formation of different types of division of labor in ants. Methylation is relatively conserved in genes related to grade differentiation and developmental changes such as reproduction, telomere maintenance, and non-coding RNA metabolic regulation. And the unusual epigenetic phenomenon of monoallelic methylation was also found in ants, which is the same as the genomic imprinting phenomenon in vertebrates. Which allele in the allele is methylated is deeply correlated with the social hierarchy of the ant. Therefore, methylation of the ant genome plays an essential role in both its biological functions and the generation of hierarchical differentiation.

2.2 Differential gene expression

In 1910, entomologist Wheeler proposed the concept of 'superorganism'. Ants can be regarded as a 'superorganism', and each ant is analogous to a cell group in a multicellular individual. For example, workers can be regarded as the 'body cells' of the individual, and the queens responsible for reproduction in the group can be regarded as germ cells'. Consistent with the concept of 'superorganism', studies have shown that the individual development process of ants has something in common with the process of cell differentiation, and both follow the Waddington epigenetic regulation model. In this study, the transcriptome of workers and queens was analyzed, and it was found that the grade differentiation and cell differentiation of workers and queens were similar [3].

In this study, Pharaoh ants and leaf-cutting ants were taken as examples. By sequencing the transcripts of two different castes of queens and workers in the population, the expression profiles of ant individual development and differentiation were drawn (Fig. 1). This study reveals, on the one hand, that the developmental process of ants coincides with the Waddington epigenetic model, i.e., with the increase of developmental time, there is an increasing difference in gene expression between different classes of ants and an increasing convergence of transcriptomes between individuals of the same class. The difference between queen and worker transcripts can be summarized as the channelization effect of differentiation, that is, the development of different levels of ants will be carried out in specific differentiation channels and a specific differentiation direction. On the other hand, the study found that the channeling genes of queens and workers are distributed in different parts, and their gene expression is not to adapt to natural selection at the individual level, but to adapt to the environment at the group level with the concept of superorganism. For example, in the queen ant responsible for marriage flight and reproduction in the colony, the canalization genes are mostly expressed in the parts related to the ovary and wings. Workers, who are responsible for the daily operation of the ant colony, have canalized genes that are mostly expressed in the brain.

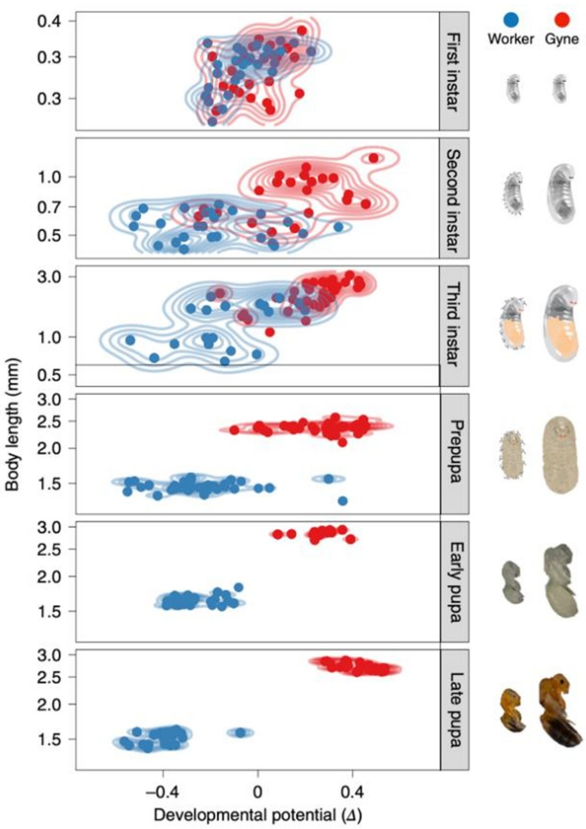

Fig. 1. Individual differential expression map of ants.

The differences in gene expression between worker ants and queen ants are increasing, while the transcriptomes of individuals of the same rank are getting closer and closer.

Compared to worker ants, queen ants are more conservative in their development and have a higher degree of canalization. The gene expression profiles of worker ants varied considerably between species, whereas queens were mostly similar; worker ants within

 https://doi.org/10.1051/bioconf/202414202002

the same species showed greater variability compared to queens. Among them, the Freja gene plays an essential role in the queen's canalization process, which gives the queen a strong reproductive ability. The Freja gene only acts on the ovary of the queen. When this gene is removed, the shape of the queen tends to be similar to that of the worker ant, showing a significant reduction in body size and abnormal wings, and the development of the ovary is also affected.

This study revealed the reasons for the hierarchical differentiation of ants at the transcriptome level. Different levels of ants represent a cell group in the 'superorganism', thus linking the 'channelization' pathway of different levels of ants to cell differentiation. In addition, this study revealed Freja, a key gene that regulates the behavior of queen ants, which enables the queen to acquire behaviors associated with her rank, illustrating the importance of key genes for the regulation of ant rank differentiation. In conclusion, the above research is of great significance to reveal the generation and regulation of ant hierarchical differentiation.

2.3 Brain specificity

The brain specificity of ants is also highly correlated with the level and behavioral differentiation of ants [4]. Some researchers analyzed the single-cell transcriptome data of the brains of workers, queens, virgin breeding ants, and male ants of pharaoh ants, and constructed high-precision single-cell maps of the brains of different grades of ants (Fig. 2). By comparing the brains of four adult Pharaoh ants, the study found that the brains of male and worker ants are extremely specialized. The brain of worker ants is highly developed in the cells responsible for processing odor information, while the optic lobe cells that process visual signals are underdeveloped. On the contrary, male ants have well-developed optic lobe cells, while mushroom somatic cells and odor-treated cells are underdeveloped. The brains of queens and virgin breeding ants are in an intermediate state. This study shows that the differentiation of ant brains is closely related to its hierarchical differentiation. Worker ants are responsible for the day-to-day functioning of the colony in an ant colony, and therefore correspondingly require functional support from their brain regions associated with learning memory, higher cognition, and odor perception; The male ant has a simpler behavior in the group, that is, it only participates in mating and reproduction, so it does not need the specialization of related brain regions such as learning and memory, advanced cognition, but needs the functional support of the visual system.

The cells responsible for processing odor information in the brain of workers are higher developed, while the visual lobe cells that process visual signals are shorter developed. The brain optic lobe cells of male ants are highly developed, while the mushroom somatic cells and odor processing cells are not developed. The brains of queens and virgin breeding ants are in an intermediate state.MB: mushroom body; mCa, the inner calyx of MB; lCa, MB lateral calyx; pedicels of ped, MB; a, α leaf of MB; lO, OL leaflet; mE, OL medulla; lA, OL layer; aL, antennal leaf; gNG, jaw ganglion; o, ocelli; mO, medial eyeball; d, dorsal; l, lateral; v, ventral.

The study revealed that the behavioral differences among different classes of ants are related to different degrees of brain specialization and that the brains of different classes of ants differ in the direction and degree of differentiation. However, the different degrees of specialization of their brains complement and coordinate with each other, which is consistent with the different but complementary social behaviors and functions performed by different levels of ants. It is proved again that ants exist as a 'superorganism' so that the whole ant colony has the functions of defense, reproduction, and foraging.

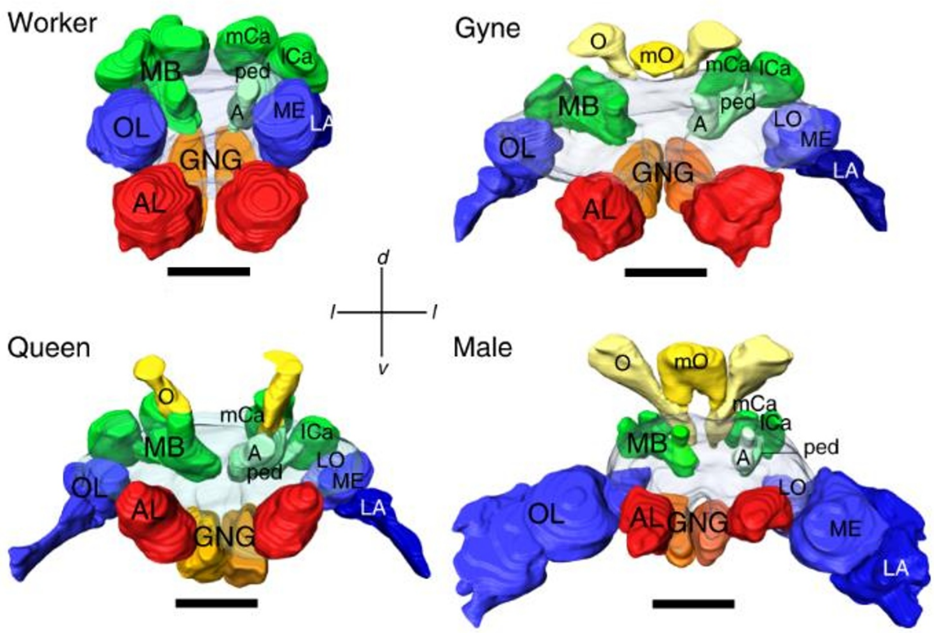

Fig. 2. 3D reconstruction of brains of different grades of ants.

3 Conclusion

This paper discusses the social habits and social division of labor of ants, expounds on how to regulate their differentiation through genes at the molecular level, and expounds on the correlation between the specificity of brain cells and hierarchical differentiation from the perspective of brain structure. At the same time, some studies have shown that the specific metabolism of the blood-brain barrier can regulate the hormone levels in the brains of ants, thus affecting their neurodevelopment and social behavior. This study also enriches the research on the mechanism of social behavior of ants, a social insect [5]. Studying the differentiation and gene regulation of ants, a true social insect has also played a certain role in elucidating the regulatory mechanism of social behavior of social animals. It is believed that in the future, there will be additional in-depth research on gene expression regulation, including histone modification, methylation modification, transcription factors, brain specificity, hormone level regulation, etc., to help explain the social programming mechanism of ants.

References

1. Shang Yuchang. (2006). Social Life of Ants. Biological Bulletin. Vol.41 No.4, 57.10.3969 / j. issn.0006-3193.2006.04.003
2. Bonasio, R., Li, Q., Lian, J., Mutti, N. S., Jin, L., Zhao, H., Zhang, P., Wen, P., Xiang, H., Ding, Y., Jin, Z., Shen, S. S., Wang, Z., Wang, W., Wang, J., Berger, S. L., Liebig, J., Zhang, G., & Reinberg, D. (2012). Genome-wide and caste-specific DNA methylomes of the ants Camponotus floridanus and Harpegnathos saltator. Current biology: CB, 22 (19), 1755–1764. https: //doi. org/10.1016/j. cub.2012.07.042
3. Qiu, B., Dai, X., Li, P., Larsen, R. S., Li, R., Price, A. L., Ding, G., Texada, M. J., Zhang, X., Zuo, D., Gao, Q., Jiang, W., Wen, T., Pontieri, L., Guo, C., Rewitz, K., Li, Q., Liu, W., Boomsma, J. J., & Zhang, G. (2022). Canalized gene expression during development mediates caste differentiation in ants. Nature ecology & evolution, 6 (11), 1753–1765. https: //doi. org/10.1038/s41559-022-01884-y
4. Li, Q., Wang, M., Zhang, P., Liu, Y., Guo, Q., Zhu, Y., Wen, T., Dai, X., Zhang, X., Nagel, M., Dethlefsen, B. H., Xie, N., Zhao, J., Jiang, W., Han, L., Wu, L., Zhong, W., Wang, Z., Wei, X., Dai, W., … Liu, W. (2022). A single-cell transcriptomic atlas tracking the neural basis of division of labour in an ant superorganism. Nature ecology & evolution, 6 (8), 1191–1204. https: //doi. org/10.1038/s41559-022-01784-1
5. Ju, L., Glastad, K. M., Sheng, L., Gospocic, J., Kingwell, C. J., Davidson, S. M., Kocher, S. D., Bonasio, R., & Berger, S. L. (2023). Hormonal gatekeeping via the blood-brain barrier governs caste-specific behavior in ants. Cell, 186 (20), 4289–4309. e23. https: //doi. org/10.1016/j. cell.2023.08.002