TRENDS IN AGRICULTURE SCIENCE

Popular Article

Vol.3 Issue 03 March 2024, Page: 1604-1611

Behavioral Implications of Color Vision in Insects

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https://doi.org/10.5281/zenodo.10900840

Vision is the art of seeing invisible, colour sense is the ability of the eye to discriminate between the different colours excited by light of different wavelength. Colour vision is the ability of an animal to use the spectral composition of light independent of intensity as a cue for decision making. Vision plays a crucial role in the lives of insects, impacting various aspects of their behavior, survival, and ecological interactions. These activities were performed using different type of eyes whose details are explained below.

In insects there are **three** types of eyes viz.,

1) **Stemmata**: These are the only visual organ of larval holometabolous insects, present in the lateral region of the head and the number varies from 1-6 on each side of the head.
2) **Dorsal ocelli**: These are found in the adult insects and the larvae of hemimetabolous insects. Mostly found on the dorsal or frontal surface of the head and appear in an inverted triangle pattern in between the compound eyes.
3) **Compound eyes**: These are the main visual organ of an insect; it comprises many hundreds to thousands of tiny facets, and each comprises ommotidium Ommatidium is divided into light gathering and light detecting parts. Corneal lens is transparent cuticle secreted by epidermal cell called corneagen cells, crystalline cone which is secreted by semper cell. Light detecting apparatus contains 7-8 light sensitive photoreceptors called retinula cell are rabdomere, together all the rhabdomere refer to rhabdom, it consists of light detecting visual pigment molecules embedded in the plasma membrane and each ommatidium is separated by other ommatidium and form an optic nerve and reach the protocerebrum.

There are two types of ommatidium

3a. Photopic ommatidium

3b. Scotopic ommatidium

These forms apposition and super position of images in insects.

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Published: 28 March. 2024
ISSN: 2583-7850

3a. Apposition type

The insects active during day time have photopic or apposition type of ommatidium because base of crystalline cone is indirectly connecting to the rhabdom, the incident light entered by corneal lens at an angle observed by screening pigments and these screening pigments prevent the entered light to scatter to an adjacent ommatidium each ommatidium serves as an individual visual unit.

3b. Super position type:

Insects which are active in night have scotopic or super position type of ommatidium, structure is similar to photopic except clear zone between the crystalline cone and rhabdom. Here the incident light focuses on base of the crystalline cone and conducted to rhabdom and the intensity of light decreases the shielding pigments contrast upward over the distal end. The light entering the dioptic apparatus one ommatidium can pass through adjacent ommatidium and form multiple super imposed images on the rhabdom and having low visual acuity and light sensitivity.

Insects use color information in different behavioral contexts it is called as visual ecology (Kooi *et al.*, 2021).

The importance of vision in insects:

1. **Phototaxis**
   - Habitat-finding and similar behaviors that do not require high resolution have mostly been studied in lepidopteran caterpillars
   - In adults, where they may be partly mediated by ocelli.
2. **Camouflage or Body Coloration**
   - Hiding the presence refers to the camouflage, this is commonly seen in the peppered moth caterpillar using the colour cues for changing their body colouration.
   - Eacock and his co-workers in 2019 conducted an experiment on "**Adaptive colour changeand background choice behaviour in peppered moth is mediated by extra ocular photoreception**" and studied morphological, behavioural and gene expression experiments to investigate the role of extraocular photoreception in colour-changing *B. betularia* larvae.

Dermal photoreception is the ability to perceive photic information through the skin independently of eyes.

Blind folding: black acryl paint applied on lateral ocelli and prevent the entry of light.

Gene expression: four final instar larvae and four adult insects are taken and using RNA later solution and TRIzol guidelines.

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Fig. 1 Blindfolded (first and third from left) and control (second and fourth from left) larvae on black and white treatment dowels.

Fig. 2 Final instar blindfolded two outermost) and control (two innermost) larvae on brown and green treatment dowels.

Whole body colour changed in the absence of visual information from the eyes, larvae change the colour with respect to the background using the visual cues through skin (dermal photoreceptors) (Fig. 1 & 2). Later, the larvae were transferred randomly on arena having different dowels and they selected appropriate dowel that are closely matched their own body colour. On an average of 75-80% of brown larvae close to rest on browndowel. 70-80% of green larvae choose to rest on green dowel these evidence shows that there is no effect of blind folding (Fig. 3).

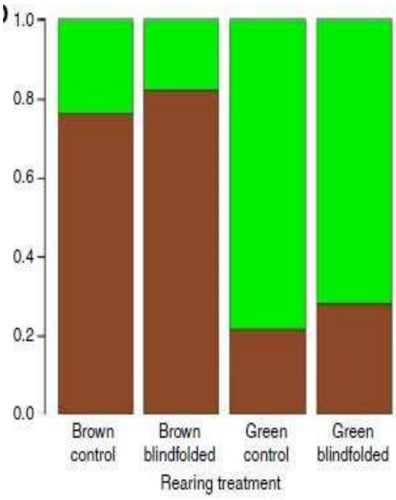

Fig. 3 Preference towards the dowel by a larvae

Similarly, investigated the molecular basis of the morphological and behavioural response, analyzed key genes involved in visual perception in head dermal tissues of larvae and adult.

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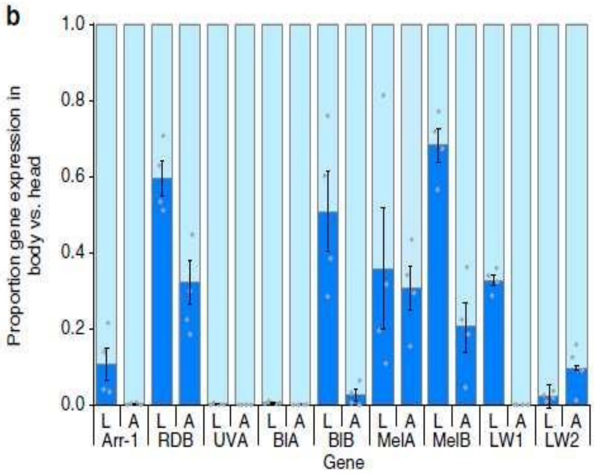

L= larva, A= adult, Arr-1 = arrestin-1, RDB= retinal degeneration B, UVA= ultraviolet wavelength sensitive opsin isoform A, BlA = blue wavelength sensitive opsin isoform A, BlB = blue wavelength sensitive opsin isoform B, MelA = melanopsin isoform A, MelB= melanopsin isoform B, LW1 = long wavelength

Fig. 4 Genes involved in visual perception of a larva.

Identified opsin sensitive to UV (UVA&UVB) Blue (BLA&BLB) long wavelength (two gene LW1&LW2) melanopsin (A&B) arrestin (1&2) retinal degeneration B (RDB) respectively and these are essential for photo transduction.

Expression of these genes are not only found in the eyes but also found in the whole body of larvae and adult. Dermal expression of photoreceptors is more in larva compare to adult. This study concluded that experimental and control larvae were equally able to change appearance and choose the appropriate resting background and shows they are capable of spectrally sensitive extra ocular photoreception.

3. **Skylight Compass**

The color of light is used as part of a sky compass by locusts, bees, and dung beetles.

4. **Detection of Shelters and Landmarks**

- Insects likely use achromatic intensity cues for flight control, the use of color for landmark navigation has been suggested. Bees can also use color to find the nest entrance.
- Somanathan and his co-workers in 2008 conducted experiment on "**Nocturnal bees land mark colour in star light**". Outdoor experiments conducted at natural nests within Bhimashankar Wildlife Sanctuary, Maharashtra State, in the Western Ghats of India.

➢ Experiments performed when bees started flying (6-7pm) continued until 03:00.

➢ Bees exiting and returning to the nest were observed using infrared-sensitive night-visionequipment and recorded on an infrared-sensitive Sony camcorder (TRV130E).

They trained at two nests to find their nest entrance centered behind a yellow square landmark ona large plywood wall. They were tested with four additional colour landmarks.

- **Test 1:** brighter and darker shades of yellow (Y1, Y2) and two shades of grey (Gr1, Gr2)

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- **Test 2:** two shades of green (Ge1, Ge2) and the same two shades of grey

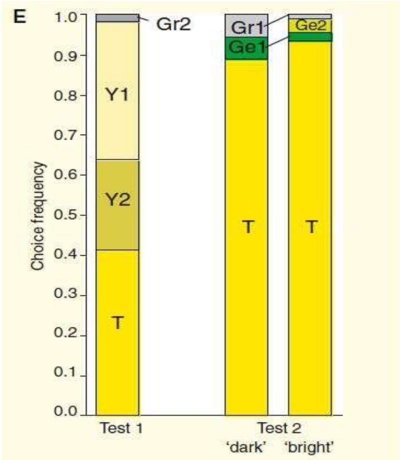

Fig. 5 Preference of bees towards the different cues

In test 1, bees chose darker and brighter yellows (Y1, Y2) as often as the training yellow (T) showing that they neglected intensity-related cues, while grey was chosen only once.

In Test 2, bees discriminated the training yellow from both green (Ge1, Ge2) and grey (Gr1, Gr2) and in darkest condition the bees choose training colour.

This evidence shows that bees discriminated the landmarks using colour rather than intensity related cue.

5. **Detection of Food Sources**

- Insect pollinators detect and discriminate flowers by means of colour.
- In particular, solitary species express spontaneous preferences guiding them to their first flower and many species learn flower colors after one or a few rewarded visits.
- Blood-sucking horseflies are repelled by long-wavelength light and attracted by UV and blue light, which helps them to discriminate host.

6. **Detection of Ovipositional Substrate**

- Many herbivorous insects express a color preference that helps them to find optimalovipositional substrate
- Butterfly species with multiple red-sensitive photoreceptors may be able to detect thenarrow chlorophyll-dominated reflectance spectrum of young leaves
- Red receptors are crucial for female lycanids to identify the larval food source thus avoidolder leaves as ovipositional substrate, which is expected to increase offspring fitness.

7. **Mate Choice**

- Conspicuous body coloration can evolve as an aposematic signal to predators.
- Color vision systems found in many butterfly taxa are presumably related to mate choice.

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- Perching butterfly males pay attention to the colours of stationary females by the wing colouration.

Praagh and his co-workers in 1980 worked on "**Drone bee fixate the queen with dorsal frontal part of their compound eyes**". Investigated the chasing behavior of drones and compound eyes which is used for the fixation of the queen during chasing.

- The drones *(Apis mellifera carnica)* were filmed with a 16 mm camera and queen tethered to a fishing line and elevated 2 m above ground level.
- The camera was positioned sufficiently far away from the queen to allow almost horizontal observation of the flight behaviour of the drones
- The vertical angle α under which the queen was seen by a chasing drone was evaluated (Fig. 6).

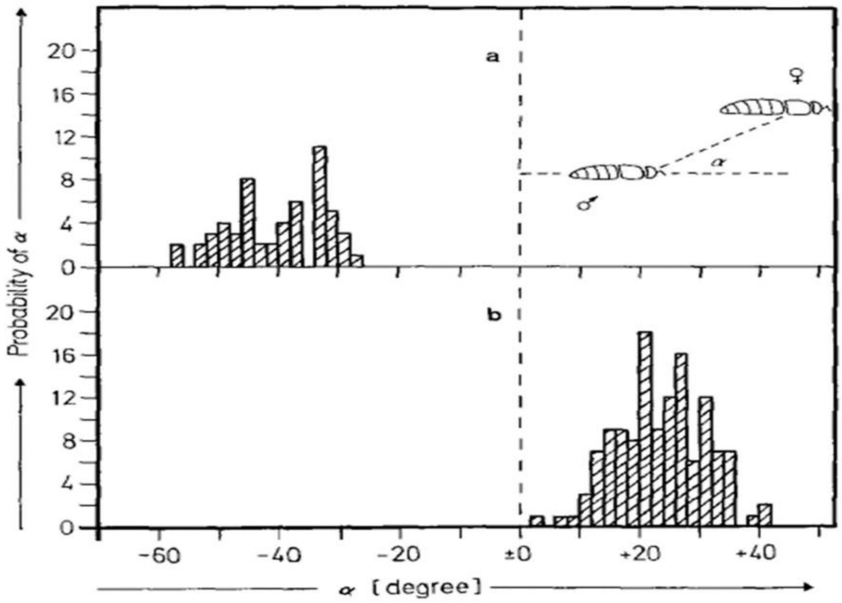

Fig. 6 a). Histogram of the vertical angle α under which the landing spot is seen by a drone bee during one typical landing period. b). Histogram of the vertical angle α under which the queen is seen by a drone bee during one typical chasing period.

- Drones appear to have two different systems for the fixation of objects.One coinciding with the lower frontal part of their field of view. This system is apparently used tofixate
- for example, the entrance of the hive before landing on it. The other system, situated in the upper frontal part of drone bees only seems to serve sexual pursuit. This sex-specific system must bedesigned to enable fixation of the queen (Fig. 6).

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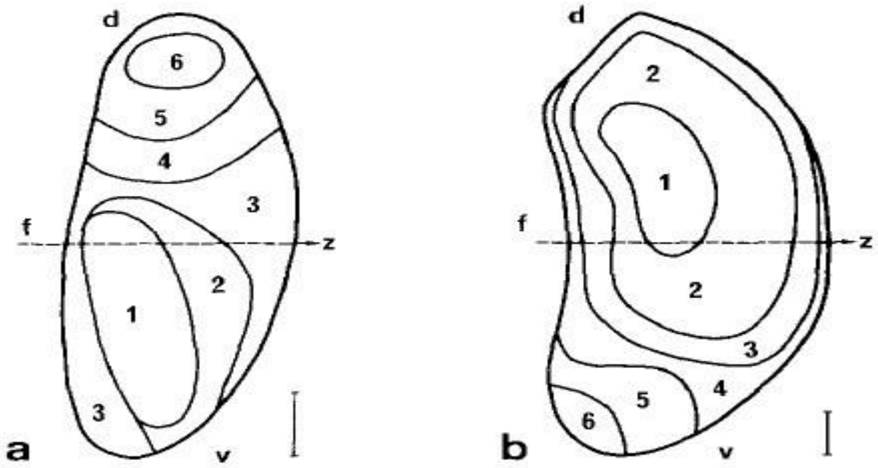

Fig. 7 Distribution of the different facet sizes in the eye of worker (a) and drone bee (b).

An area of large facets (facet diameter 17.7μm) extends from the ventral to the fronto-median eye region. Additionally, a distinct gradient runs from the ventral to the dorsal pole of the eye. The smallest facets, 15μm in diameter, are arranged in a circular area at the dorsal pole of the eye.

In the drone bee's eye, with a total facet number of 9,973 + 56 (n =4), the largest facets, with a diameter of over 31μm, are found in the dorso-frontal eye region (Fig. b). From there a dorso-ventrally oriented gradient to the smallest facets (diameter 18.5μm) in the ventral part of the eye is noted.

The largest facet lens of drone was 31μm found in the dorso-frontal region of the eye this concludes the size of facet enhances the angular vision and resolution and having highest absolute sensitivity it enhances the drone to fixate the queen.

Overall, vision is a vital sensory modality for insects, enabling them to perceive and respond to their surroundings effectively, thus enhancing their chances of survival and reproductive success in diverse ecological niches.

Conclusion

- Insects use compound eyes for detection of light and they are observed by the visual pigments present in the rhabdomere
- These signals are transferred through a series of connection from neuropiles to protocerebrum
- The optic lobes consist of successive neuropils: the lamina, the medulla and the lobula complex
- The signals are used in the visual ecology like land mark recognition, mate choice, selection of oviposition and many behavioral functions.

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