Aquaculture 497 (2018) 253–259

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Review

Phototactic behavior of live food rotifer *Brachionus plicatilis* species complex and its significance in larviculture: A review

Hee-Jin Kim[a,*], Jae-Seong Lee[b], Atsushi Hagiwara[a,c]

[a] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, Bunkyo 1-14, Nagasaki 852-8521, Japan
[b] Department of Biological Science, College of Science, Sungkyunkwan University, Suwon 440-746, South Korea
[c] Organization for Marine Science and Technology, Nagasaki University, Bunkyo 1-14, Nagasaki 852-8521, Japan

ARTICLE INFO

Keywords:
Rotifera
Brachionus spp.
Eyespot
Phototaxis
Larviculture

ABSTRACT

We review a recent progress of photophysiological studies in the rotifer *Brachionus plicatilis* species complex. The rotifers have a light sensor i.e., eyespot inducing phototactic behavior. For the rotifer *B. plicatilis* sp. complex, the eyespot efficiently absorbs the light wavelength ranging from 450 to 550 nm. The function of eyespot is affected by diet species from 30-day batch cultures fed by either microalgae *Nannochloropsis oculata* or baker's yeast *Saccharomyces cerevisiae*. By feeding baker's yeast, rotifer eyespot gradually lost its function: area (5.5 times) and absorbance (2.2 times) decrease compared to those fed by *N. oculata*. Phototactic behavior and reproductive characteristics of the rotifer *B. plicatilis* sp. complex varied with different light wavelengths and intensities. The rotifers show light wavelength dependent phototaxis associated with the reception of an eyespot. For the phototactic behavior in horizontal level, light intensity is also a significant factor to regulate phototaxis. The rotifers show strong positive phototaxis under blue (peaks at 470 nm), green (525 nm), and white (460 and 570 nm) lights at 0.5 W/m^2. Rotifer reproduction is also affected by light wavelength and intensities. Asexual reproduction of rotifers is accelerated by green and red lights at 0.5 W/m^2. On the other hand, active sexual reproduction is observed with blue light at 1.4 W/m^2. Under a certain light condition inducing active phototactic behavior, the rotifers show continuous swimming movement without attaching to substrates. The different behaviors associated with light conditions affect the reproductive characteristics of rotifers. The regulation of live food distribution is significant for feeding efficiency of fish larvae. The efficient feeding promotes larval growth and survival: hence it is a significant factor for successful larviculture. Fish larvae also show different phototactic behavior related to light wavelengths and intensities. Therefore, the distributions of fish larvae under the applied light conditions should be considered.

1. Introduction

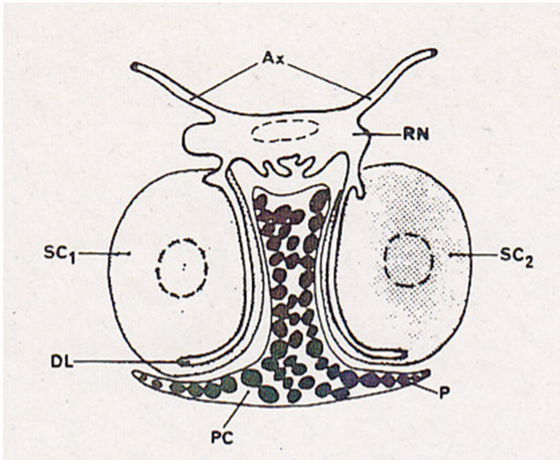
Aquatic organisms living near the surface like rotifers *Brachionus plicatilis* species complex are overly exposed to sunlight, and exhibit the phototactic responses such as the diel and ontogenetic vertical distribution (Forward, 1988; Ringerberge, 1999; Burks et al., 2002). Pelagic organisms exhibit peculiar phototactic behavior, and usually differs according to light sensor (George and Fernando, 1970; Richard and Forward, 1988). The light sensor instructs the movement of possessors which can detect direction of light, while not form visible images (Jékely et al., 2008). The phototactic behavior of rotifers is also significantly influenced by the characteristics of light sensor eyespot. Therefore, this review firstly characterizes rotifer eyespot with light wavelength-dependent absorbance.

The light plays an important role in the behavior of numerous plankton species with phototaxis (Forward, 1988; Buskey et al., 1989; Storz and Paul, 1998). The light wavelength and intensity have significant role in the phototactic behavior of zooplanktons (Richard and Forward, 1988). Locomotor reactions of rotifers to qualitative or quantitative variations in light conditions can be classified into two categories: oriented reactions (phototaxis) that can be positive or negative, and non-oriented reactions (photokinesis) that are subdivided into orthokinesis (modification of linear speed) and klinokinesis (modification of the rate of change of direction, Mimouni et al., 1993). We secondly reviewed recent studies on phototactic behavior of the euryhaline rotifers under different light conditions (various light wavelengths and intensities).

The monogonont rotifers have a cyclically parthenogenetic life cycle with both sexual (mictic) and asexual (amictic) reproduction and it is affected by various internal and external factors (Hagiwara et al., 2007;

* Corresponding author.
E-mail address: heejin@nagasaki-u.ac.jp (H.-J. Kim).

https://doi.org/10.1016/j.aquaculture.2018.07.070
Received 29 December 2017; Received in revised form 6 July 2018; Accepted 31 July 2018
Available online 01 August 2018
0044-8486/



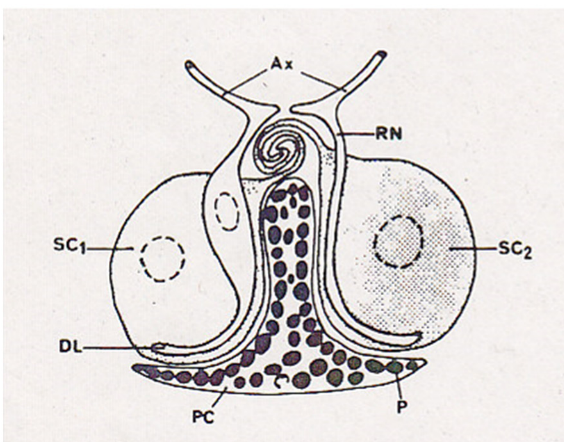


Fig. 1. Diagram of the cerebral eye of freshwater rotifer *Brachionus calyciflorus* (A) and euryhaline rotifer *Brachionus plicatilis* sensu sticto (B) with an electron microscope. Ax, axon; PC, pigment cup; P, platelets; SC1, SC2, sensory neurons; RN, relay neuron; DL, dendritic lamellae (Clément et al., 1983).

Gilbert, 2010). Asexual reproduction predominates the rotifer life cycle, while sexual reproduction results from stimulation by various environmental factors such as light, temperature and food density. In sexual reproduction, mictic females produce haploid males, or if fertilized, they produce diploid resting eggs (Gilbert, 2004, 2010; Hagiwara

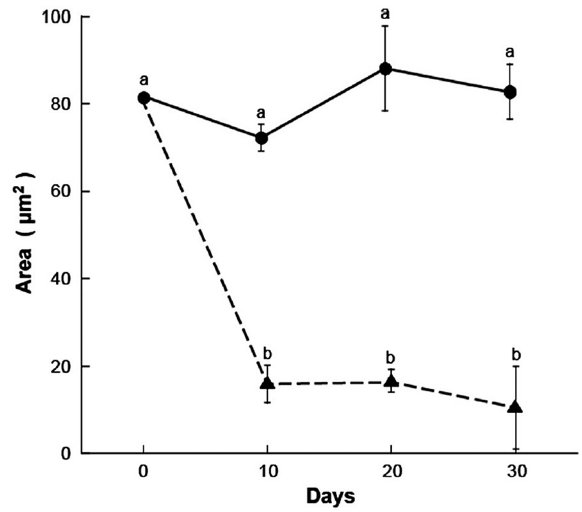


Fig. 2. Variation of rotifer eyespot area with different two diets *Nannochloropsis oculata* (closed circle) and baker's yeast (*Saccharomyces cerevisiae,* closed triangle). Plots and bars indicate the means and standard deviations, respectively. Different alphabetical letters on the plots denote significant differences (a > b, Tukey-Kramer post hoc test, $p < 0.05$, $n = 3$) (Kim et al., 2014b).

et al., 2007). The produced resting eggs can be used as *Artemia* cyst in aquaculture. To date, light effects on rotifer reproduction have been defined for the efficient production of resting eggs and rotifer propagation. In this review, the effects of light conditions on the reproduction of euryhaline rotifer *B. plicatilis* sp. complex was thirdly debated related to the movement pattern of rotifers. Lastly, the predator effects and the application methods were discussed for the further experiments.

2. Light sensor of rotifers

The light sensors detect light signals with visual pigments and the detected signals can modulate the phototactic behavior of organisms (Jékely, 2009). The euryhaline rotifer *B. plicatilis* species complex has a red eyespot which has a similar structure to the freshwater rotifer *Brachionus calyciflorus* with only two differences in relay neuron and endoplasmic reticulum (Fig. 1, Clément et al., 1983). As the common planktonic invertebrate, the monogonont rotifer *Brachionus*, has a cerebral eye (red eye spot) consisted of two types of pigment-bearing cells: one epithelial cell cup containing accessory pigment and one or more sensory neurons (sensory pigment) with membranous structure (Clément, 1980; Clément et al., 1983; Cornillac et al., 1983). Through the joint action of these two pigments, they can determine the direction, as well as light wavelength and intensity (Clément et al., 1983). The main visual pigment of rotifer eyespot has been suggested as

Table 1
Putative opsin-relevant genes identified in the genome database of *Brachionus koreanus*. The values of three parameters i.e., E-value, identities, positives were analyzed by in silico BLASTx search in the NCBI database (Kim et al., 2014b).

Gene	Length (bp)	Accession no.	Species (GenBank No.)	E-value	Identities (%)	Positives (%)
Blue-sensitive opsin-like	267	KF885941	*Latimeria chalumnae* (XP_006001498)	7E-10	41	58
C-opsin	882	KF885939	*Tribolium castaneum* (NP_001138950)	4E-38	33	54
Ciliary opsin	216	KF885940	*Platynereis dumerilii* (AAV63834)	2E-07	33	58
Ciliary opsin	624	KF885942	*Terebratalia transversa* (ADZ24786)	1E-31	36	57
GQ-rhodopsin	267	KF885938	*Daphnia pulex* (EFX63569)	8E-09	36	58
Melanopsin	747	KF885936	*Crassostrea gigas* (EKC19391)	7E-35	32	54
Melanopsin	684	KF885946	*Lottia gigantean* (ESO95853)	9E-27	32	47
Melanopsin	276	KF885945	*Myotis brandtii* (EPQ10710)	2E-11	36	58
Opsin	273	KF885944	*Schmidtea polychroa* (AFB74475)	1E-12	40	59
Opsin (encephalopsin, panopsin)	207	KF885937	*Danio rerio* (CAX13063)	7E-10	43	64
Peropsin	792	KF885943	*Hasarius adansoni* (BAJ22674)	3E-34	31	50
Rhabdomeric opsin	1101	KF885935	*Platynereis dumerilii* (AGL94565)	2E-53	31	53