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# The effect of photoperiod and light quality on *Macrolophus pygmaeus* Rambur (Hemiptera: Miridae) nymphal development, fecundity and longevity

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## HIGHLIGHTS

- *M. pygmaeus* reproduced in 8, 11, 13 and 16 h daylengths without diapause.
- Shorter photoperiods prolonged pre-adult development regardless of the light source.
- Fecundity increased with decreasing photoperiod irrespectively of light quality.
- 16-h day including 5 h of red LED-light did not affect negatively the bug's biology.
- Short photoperiods could be used to rear *M. pygmaeus* commercially.

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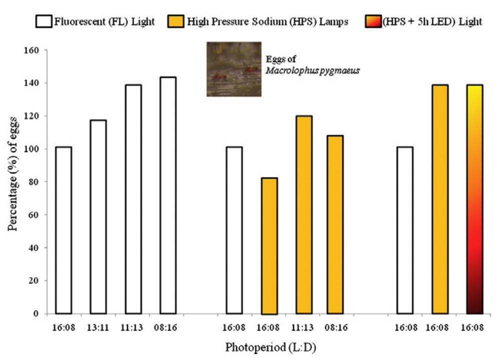
## GRAPHICAL ABSTRACT




## ABSTRACT

Development time of immatures, fecundity, longevity and egg hatching of the predatory bug *Macrolophus pygmaeus* were studied over three years under artificial lighting in growth chambers to assess if light quality and photoperiod could explain its poor establishment in winter tomato crops at northern latitudes. In the first year, the effect of photoperiod was assessed using fluorescent lamps (FLs) at 16L:8D, 13L:11D, 11L:13D and 8L:16D. In the second year, the effect of light quality was assessed by producing the 16L:8D photoperiod with FLs, high pressure sodium lamps (HPSLs) and HPSLs complemented with red (R) light emitting diodes (LEDs) (11 + 5 h, HPSLs + R). In the third year, 16L:8D, 11L:13D, 8L:16D photoperiods were produced by HPSLs and 16L:8D with FLs. In all the treatments, females from the first, second and third generation oviposited, and their eggs hatched pointing that *M. pygmaeus* does not undergo reproductive diapause. In general, shorter photoperiods prolonged the development time of immatures regardless the light source, whereas fecundity increased with decreasing photoperiod irrespectively of light quality. In FLs, fecundity was significantly lower than in HPSLs alone or in HPSLs + R in one experiment, whereas light quality (FLs and HPSLs) did not affect fecundity in the other experiment. The results suggest that HPSLs as such do not adversely affect reproductive biology of the bug except for the pre-adult development time, and that part of the long photoperiod could be replaced with red LEDs without negatively affecting the bug's biology. The 16-h light period produced by artificial lighting in year-round tomato production, however, is not optimal for the fecundity of *M. pygmaeus*, and fertility may also decrease. Further research is needed from greenhouse winter conditions where the bugs perceive and may respond also to the natural short photoperiod.



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## 1. Introduction

In northern latitudes, where light and temperature are limiting factors for plant production, the practice of year-round production of vegetables is possible thanks to the implementation of heated greenhouses with artificial lighting. Artificial lighting technologies have been developed so far to fulfil the plants' requirements, and improve crop yield and quality (Gruda, 2005, for a review) without considering potential effects on higher trophic levels. The conditions created in the greenhouse include long photoperiods ranging between 16 and 22 h, or even 24 h in some crops (Vänninen et al., 2011), and spectra that differ from natural sunlight. Such conditions may affect arthropods directly (Johansen et al., 2011) or indirectly via qualitative changes in the plant (Vänninen et al., 2011). Light intensity, quality and quantity (photoperiod) play important roles in arthropod's biology and behaviour. For example, light is involved in the induction and termination of diapause, growth rate, mating, fecundity, sex ratio and egg/adult eclosion (for example Depner, 1962; Gillespie and Quiring, 2005; Hamdan, 2006; Philogene and McNeil, 1984; Suzuki et al., 2008). The adverse effects of light on plant antagonists can be exploited to improve pest management (Díaz and Fereres, 2007; Schuerger and Brown, 1997). Nevertheless, artificial lighting may also affect predators and parasitoids released in greenhouses as biological control agents (Johansen et al., 2011), resulting in incompatibility between different pest management strategies.

*Macrolophus pygmaeus* and *M. melanotoma* (Costa 1853) *(*syn. *M. caliginosus)* (Hemiptera: Miridae) are two carnivorous species native to the Mediterranean area. *M. pygmaeus*' natural distributional range covers Tadzhikistan in the east, the Azores Islands to the west, Finland to the north, and Algeria to the south (Kerzhner and Josifov, 1999). Like *M. melanotoma*, it feeds on a wide range of arthropods such as whiteflies, aphids, spider mites, butterfly eggs and leafminers (Arnó et al., 2003; Hansen et al., 1999; Margaritopoulos et al., 2003; Perdikis and Lykouressis, 2004, 2002; Riudavets and Castañé, 1998) and are, therefore, important in the biological control of such pests. *M. melanotoma* is found throughout the year on *Dittrichia viscose* (Asteraceae) and it seems to overwinter as nymphs in Greece (Perdikis et al., 2007). Likewise, in Spain it overwinters on several plants from where it colonizes greenhouses in spring and exerts biological control on various greenhouse pests (Alomar et al., 2002; Castañé et al., 2004). In the conditions of Southern France, *M. melanotoma* do not undergo reproductive diapause (Carayon, 1986). However, short days (8L:16D) or total darkness have been reported to affect the embryonic development of *M. melanotoma*, a situation that is reverted when the eggs are incubated in long days (16L:8D) (Hamdan, 2006). Identification of *M. pygmaeus* and *M. melanotoma* based on different body measurements shows a great number of misconceptions (Martinez-Cascales et al., 2006a) and biocontrol agents marketed under the name *M. melanotoma* have in certain cases turned out to be *M. pygmaeus* (Martinez-Cascales et al., 2006b). Actually Castañé et al. (2011) assume that publications referring to *Macrolophus* in vegetable crops should have studied *M. pygmaeus.*

In Finland, *Macrolophus* bugs are introduced seasonally in year-round and seasonal tomato greenhouses, and are the most important component of the biological control programs of the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood 1856) (Hemiptera: Aleyrodidae). Recent observations in Finnish greenhouses have left in evidence that the commercial populations of *Macrolophus* often decrease in winter despite supplementary feeding with moth eggs and artificial lighting. Since temperature and humidity are controlled in northern (including Scandinavia, Belgium, Netherlands and Canada) year-round greenhouses, and conditions are kept all time at levels that are optimal for crop plants' requirements, we hypothesized that the short naturally occurring photoperiod during winter months in northern latitudes or the quality of the artificial lighting could be inadequate for this species. The most popular lamp type for supplementing light in greenhouses is the high-pressure sodium lamp (HPSL). The spectrum of these lamps concentrates in the yellow–red light frequencies giving emission peaks of 51% at 500–600 nm, 40% at 600–700 nm (red) and only 9% at 400–500 nm (blue) (Tazawa, 1999). Therefore, HPSL-produced light is qualitatively different to natural day light. The possible effects of the different light qualities on arthropods is further reviewed and discussed Johansen et al. (2011).

Most of the biological studies of the *Macrolophus* species have not strictly addressed the effect of light (but see Hamdan, 2006; Perdikis et al., 1999). Insects are often thought to be blind to red colour As *M. pygmaeus* is a night active species, we hypothesized that it could benefit of shorter photoperiod and that the photoperiod could be expanded by red lights without causing negative effects to the predator and still fulfilling the demands of the plant. Light emitting diodes (LEDs) have been proposed as an efficient alternative lighting source to supplement natural light in horticultural crops (Morrow, 2008), and are expected to become the new artificial lighting source in greenhouse production in the near future. This expectation urges the need to assess LED lighting on herbivores and biological control agents usually released in greenhouses. Here, we report the results of growth chamber experiments conducted over three consecutive years (2009–2011) between October and February. We measured selected biological parameters of *M. pygmaeus* in response to different photoperiods produced by luminaries with different light conditions (quality and photoperiod) in an attempt to understand whether photoperiod and light quality play role in the establishment success of the bug populations in Finnish greenhouses during winter months.

## 2. Materials and methods

### 2.1. Plant material

Tobacco plants (*Nicotiana tabaccum*) cv. Samsun were used for all three experiments. Plants were produced weekly under greenhouse conditions (21 ± 1 °C, 16L:8D) to provide plants to the bug rearing and experiments. Plants were watered with a standard fertilizer solution (N-P-K 14-5-21, 1 g/l, Kekkilä, Finland) two to three times a week.

### 2.2. Insect rearing

A colony of *M. pygmaeus* was established on tobacco plants from individuals obtained from a commercial supplier. According to the supplier, the population originated in Southern France. A new colony was initiated separately for each of the three experiments, always with insects from the same supplier. Despite that the insects were bought under the commercial name of *M. caliginosus*, the species in all three experiments was identified as *M. pygmaeus* according to the egg description by Perdikis and Lykouressis (2000) and Perdikis et al. (2003). The species was also confirmed by Dr. Veikko Rinne (Zoological Museum, University of Turku, Finland) who identified adults from our colonies as *M. pygmaeus.*

Adults were allowed to mate and oviposit on tobacco plants placed in transparent Perspex cages (33 × 33 × 60 cm). Plants with eggs were cut at the base, and transferred into clear plastic boxes (24 × 18 × 7.5 cm) to prevent predation of the emerging nymphs by adults. A buckwheat layer (200 ml) was added for the nymphs to hide in. Nymphs were kept in the boxes until they reached