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A brief review of mycangia and associated yeast symbionts in British stag beetles

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Abstract

Mycangia are exoskeletal saccate structures that harbour symbiotic yeasts or other fungi. Such structures have been found in some wood-boring beetles, bark beetles, leaf-rolling weevils, a lizard beetle and wood wasps. Recently, a female-specific, yeast-harbouring mycangium has been discovered in several species of Japanese stag beetle. DNA analyses of yeasts from the mycangia of these lucanids have revealed the presence of a specific yeast genus, *Scheffersomyces*, which has been shown to utilise xylose. The larval gut of some of these lucanids contains the same *Scheffersomyces* yeast symbionts as those present in the mycangia of the imagos. Vertical transmission of these yeast symbionts from adult to larva has also been suggested. Stag beetle larvae feed predominantly on decaying, broadleaf wood (hardwood). Wood is known to be one of the most difficult organic materials to digest. Yeast cells in the larval gut most likely assist in the digestion of wood, especially hardwood hemicelluloses that consist predominantly of the polysaccharide xylan, the breakdown of which produces xylose. This paper focuses on the more recent discovery of mycangia and their associated symbiotic yeasts in the three extant stag beetle species present in Britain, *Lucanus cervus, Dorcus parallelipipedus and Sinodendron cylindricum.*

Keywords: Stag beetles, female-specific mycangia, yeast symbionts, xylose utilization.

Mycangium

The mycangium found in stag beetles is a pocket-like organ that is situated in the abdomen of females, where it lies immediately above the rectum (Figs 1, 2 & 3) (TANAHASHI *et al.* , 2010; HAWES, 2013; FREMLIN & TANAHASHI, 2015; TANAHASHI & HAWES, 2016). Twenty two Japanese stag beetle species and three species of European stag beetle have been examined, the females of which all had an abdominal mycangium located above the rectum (TANAHASHI *et al.,* 2010; HAWES, 2013; FREMLIN & TANAHASHI, 2015; TANAHASHI & HAWES, 2016). No males from the 25 species examined had a mycangium located near the rectum. (HAWES, 2013; TANAHASHI *et al.,* 2010). The female-specific mycangia are formed by an infolding of the flexible membrane that connects the eighth and ninth abdominal segments (TANAHASHI *et al.,* 2010; HAWES, 2013; TANAHASHI & FREMLIN, 2013). Like the pockets in a pair of trousers, the flexible, membranous mycangium is constructed such that it can be turned inside-out, a process which has been observed by Fremlin and Tanahashi (FREMLIN & TANAHASHI, 2015). These mycangia appear to function as storage organs for their larval symbiotic yeasts, which are capable of utilizing the sugar xylose, a breakdown product of wood (TANAHASHI *et al.,* 2010; HAWES, 2013; TANAHASHI & HAWES, 2016). For mycangium yeasts to be passed to their larval offspring, it has been suggested that the females need to transmit their mycangium yeasts to decaying wood, or close to where she deposits eggs (TANAHASHI *et al.,* 2010). Transmission of yeasts from stag beetle larva to female mycangium (vertical transmission) is probably explained by the behaviour of the newly formed female inside the larval cocoon, inside which the larva pupates. During this phase the female turns her mycangium inside-out and rubs it around the inner wall of the cocoon, suggesting that by performing this action it is able to acquire the yeast symbionts left by the larva, which evacuated its gut in the cocoon before pupation (TANAHASHI & FREMLIN, 2013; FREMLIN & TANAHASHI, 2015).

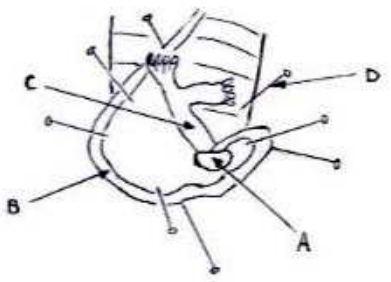

Fig. 1. Drawing illustrating a dorsal view of the mycangium and other organs in the abdomen of a *Lucanus cervus* female. A. mycangium, B. gut, C. oviduct, D. dissection pin.

Fig. 2. Dorsal view of dissected *Lucanus cervus* female (elytra removed) showing the mycangium, gut and oviduct (see Fig.1).

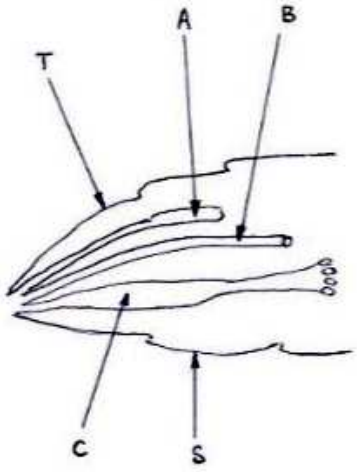

Fig. 3. Diagrammatic representation of a vertical section through the midline of the rear end of a *Lucanus cervus* female (elytra removed) showing the relative positions of the mycangium (A), gut (B) and oviduct (C). T and S refer to tergite and sternite

British stag beetles and associated yeasts

Three species of stag beetle (Coleoptera: Lucanidae) occur in Britain: the stag beetle *Lucanus cervus,* lesser stag beetle *Dorcus parallelipipedus* and the rhinoceros, or horned stag beetle *Sinodendron cylindricum.* A fourth species *Platycerus caraboides* was once present but is now extinct.
A female-specific mycangium (Figs. 1 & 2) and associated yeast were discovered in *L. cervus* in 2009. This yeast was later isolated and shown to utilize xylose (HAWES, 2013). Molecular phylogenetic analysis showed the yeast to be closely related to *Pichia* (now *Scheffersomyces) stipitis* (TANAHASHI & HAWES, 2016). A female-specific mycangium and associated yeast has also been found in *D. parallelipipedus*. In this case, the yeast has been identified as *Pichia* (now *Scheffersomyces*) *stipitis* (TANAHASHI & FREMLIN, 2013). Interestingly, the female-specific mycangium of the Japanese stag beetle *Dorcus rectus* also harbours *Scheffersomyces stipitis* (TANAHASHI *et al.,* 2010). More recently,

examination of *S. cylindricum* has revealed a female-specific mycangium, which contains symbiotic yeasts (TANAHASHI & HAWES, 2016). Unlike the mycangium found in *L. cervus* and *D. parallelipipedus,* each of which is associated with a single yeast species, two yeast species have been identified from the mycangium of *S. cylindricum.* One of these appears to be a novel species, while the other has been identified as belonging to the genus *Sugiyamaella.* Both of these yeasts are able to utilize xylose (TANAHASHI & HAWES, 2016). The larval mid-gut, hind-gut and caecum-like sacs of *S. cylindricum* harbour three yeasts: two *Sugiyamaella* strains and *Scheffersomyces insectosa.* These yeasts can also utilize xylose (TANAHASHI & HAWES, 2016). All yeasts were identified using DNA analysis.

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