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Current findings on the molecular mechanisms underlying anhydrobiosis in *Polypedilum vanderplanki*

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Water is an essential molecule for living organisms. However, some organisms can survive in environments which receive no rainfall for months and in which ordinary life cannot survive. How do they endure the extended dry season? The sleeping chironomid *Polypedilum vanderplanki*, which inhabits sub-Saharan Africa, exhibits extreme tolerance to complete desiccation, a process termed anhydrobiosis. During anhydrobiosis these organisms dry up and entirely shut down their metabolism. However, when the dried larvae are immersed in water, their metabolism is resumed. Interestingly, anhydrobiosis allows these organisms to tolerate not only desiccation but also high and low temperatures, the absence of oxygen, radiation, and chemical stresses. Here, we describe the mechanisms by which *P. vanderplanki* achieves anhydrobiosis revealed in our recent research.

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Introduction

Water usually accounts for approximately 60%–90% of the weight of organisms. It is essential for vital reactions including metabolism, and thus dehydration can cause serious damage or death. Most organisms are adapted to a moist environment, whereas some inhabiting xeric or semi-xeric environments have evolved to endure drought conditions. The most sophisticated example of desiccation tolerance is termed anhydrobiosis. Anhydrobiotic organisms can tolerate almost complete dehydration and abatement of their metabolic activity to undetectable level. The Dutch scientist Antonie van Leeuwenhoek first observed this phenomenon in so-called 'Animalcules', which is now known as rotifers, using a self-built microscopy in 1702 [1]. Today, anhydrobiotic organisms can be found in many taxa: bacteria, yeast, protozoa, rotifers, tardigrades, nematodes, crustacean eggs, larvae of insect, plant seeds, and resurrection plant although no anhydrobiotic vertebrates have been observed [2]. Since the first observation by Leeuwenhoek, morphology, biochemistry and physiology of anhydrobiosis have been investigated [2,3]. In this review, we focus on recent findings on the molecular mechanisms underpinning anhydrobiosis in the sleeping chironomid *Polypedilum vanderplanki* because the larva of this midge is the biggest animal capable of anhydrobiosis.

Anhydrobiosis of *P. vanderplanki*

P. vanderplanki is the only insect known to be capable of anhydrobiosis (Figure 1a). The anhydrobiotic state can be observed only in larval stage, and not in eggs, pupae, or adults (Figure 1b). It is believed that the larval period is the longest developmental stage during their life cycle and thus anhydrobiotic ability in larvae is beneficial enough for this organism to survive under drought conditions. The desiccated larvae (water content: $<2\%$) reversibly resume active life without obvious damage [4–6]. The larvae inhabit temporary pools on granite rocks in semi-arid region in Africa, namely sub-Sahara. In area of the habitat, the rainy and dry seasons are dramatically distinct, and droughts can last without any rain drops for over half a year. During these periods, pools gradually evaporate and most aquatic life gradually dies; however, *P. vanderplanki* larvae withstand by becoming to anhydrobiotic state (Figure 2). In addition, anhydrobiotic *P. vanderplanki* larvae can tolerate not only desiccation but also other environmental stresses, such as temperatures ranging from -270 to 102°C, organic solvents, high pressure, vacuum, and radiation [6,7]. Surprisingly, the dried larvae can be stored retaining revivability in outer space for 2.5 years [8].

In most insects, hypometabolic status, such as diapause and aestivation, is regulated by seasonal change through the neuroendocrine system. Thus, the brain has a pivotal role in regulation of the hypometabolic status [9]. In contrast, successful entry to anhydrobiosis in *P. vanderplanki* does not require regulation by the brain because even the decapitated (headless) larvae can be resuscitated after desiccation (Figure 1c) [10]. Indeed, isolated fat body can be kept viable in a dry state [11]. These findings indicate that the anhydrobiosis in this insect is regulated at the cellular level.