Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in
Genetics & Development

Developmental systems of plasticity and trans-generational epigenetic inheritance in nematodes

Vahan Serobyan* and Ralf J Sommer

Several decades of research provided detailed insight into how genes control development and evolution, whereas recent studies have expanded this purely genetic perspective by presenting strong evidence for environmental and epigenetic influences. We summarize examples of phenotypic plasticity and trans-generational epigenetic inheritance in the nematode model organisms *Pristionchus pacificus* and *Caenorhabditis elegans*, which indicate that the response of developmental systems to environmental influences is hardwired into the organisms genome. We argue that genetic programs regulating these organismal–environmental interactions are themselves subject to natural selection. Indeed, macro-evolutionary studies of nematode feeding structures indicate evolutionary trajectories in which plasticity followed by genetic assimilation results in extreme diversity highlighting the role of plasticity as major facilitator of phenotypic diversification.

Address
Max Planck Institute for Developmental Biology, Department of Evolutionary Biology, Spemannstraße 37, Tübingen, Germany

Corresponding author: Sommer, Ralf J (ralf.sommer@tuebingen.mpg.de)
* Present address: Department of Biology, New York University, New York, NY 10003, United States.

Current Opinion in Genetics & Development 2017, **45**:51–57

This review comes from a themed issue on **Developmental mechanisms, patterning and evolution**

Edited by **Christian S Hardtke** and **Yoshiko Takahashi**

http://dx.doi.org/10.1016/j.gde.2017.03.001

Introduction

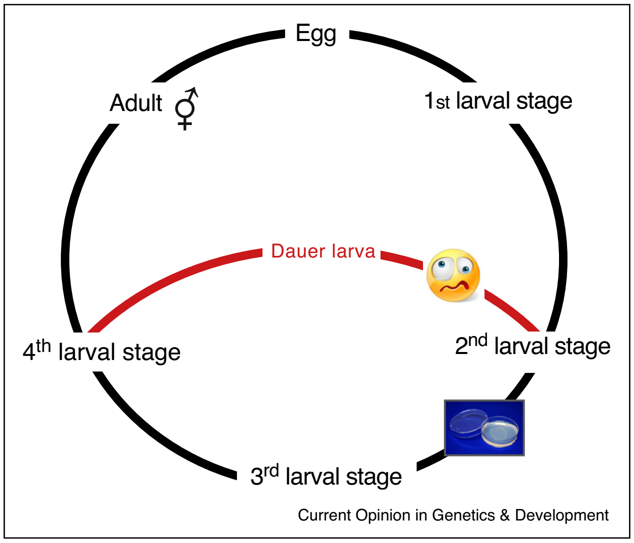
"Heredity is only the sum of all past environments." (Burbank, 1906).

Organisms adapt to their environment and to environmental variation. But while the influence of the environment on the development of organisms is obvious, environmental impact on evolution has been discussed controversially for centuries [1,2]. Ever since Darwin's origin of species (1859), Weismann's principle of the germplasm (1892) and the rediscovery of Mendel's laws after 1900, mainstream evolutionary thought holds that natural selection acts on the phenotype through genetic variation and not through environmental changes [3–5]. However, recent technical advances in selected model systems provide insight into molecular mechanisms indicating that organisms do respond to environmental variation in a sophisticated manner. Studies on phenotypic plasticity and trans-generational inheritance indicate that epigenetic information is indeed transmitted between generations and that the environment can affect genetic and epigenetic processes with phenotypic consequences for the organism [6–10]. In general, plasticity and epigenetic inheritance are well documented in plants, whereas many examples in animals remain contentious [11]. Among the exceptions are studies in the nematode model organisms *Caenorhabditis elegans* and *Pristionchus pacificus*, which, based on their short generation time (3–4 days), isogenic propagation (as self-fertilizing hermaphrodites) and undemanding dietary requirements (monoxenic *Escherichia coli* diet), provide useful laboratory systems for studying environmental influences on developmental systems (Figure 1) [12–14]. While these findings reopen old debates, they also help in providing a more balanced view on the development and evolution of biological systems. In this review, we highlight some recent studies in these two nematodes that provide insight into the molecular mechanisms of phenotypic plasticity and trans-generational epigenetic inheritance.

Phenotypic plasticity as paradigm for studying environmental influences on development

In the modern life sciences, organisms are mostly investigated under controlled laboratory conditions. These artificial laboratory environments not only differ substantially from those experienced in the wild, they also lack regular changes and heterogeneity, two hallmarks of natural environments on planet Earth at all time scales. Under natural conditions organisms have to constantly cope with changing environments and hence adaptive phenotypes are likely to be the result of natural selection acting on phenotypes in response to relentless environmental fluctuations [15]. Yet how can the influence of changing environmental conditions be investigated in the framework of modern life sciences by taking a model organism approach? One inroad is to study a phenomenon that by definition describes the influence of the environment on phenotypes, often referred to as 'phenotypic or developmental plasticity' [6,7]. Phenotypic plasticity is the property of a genotype to produce different

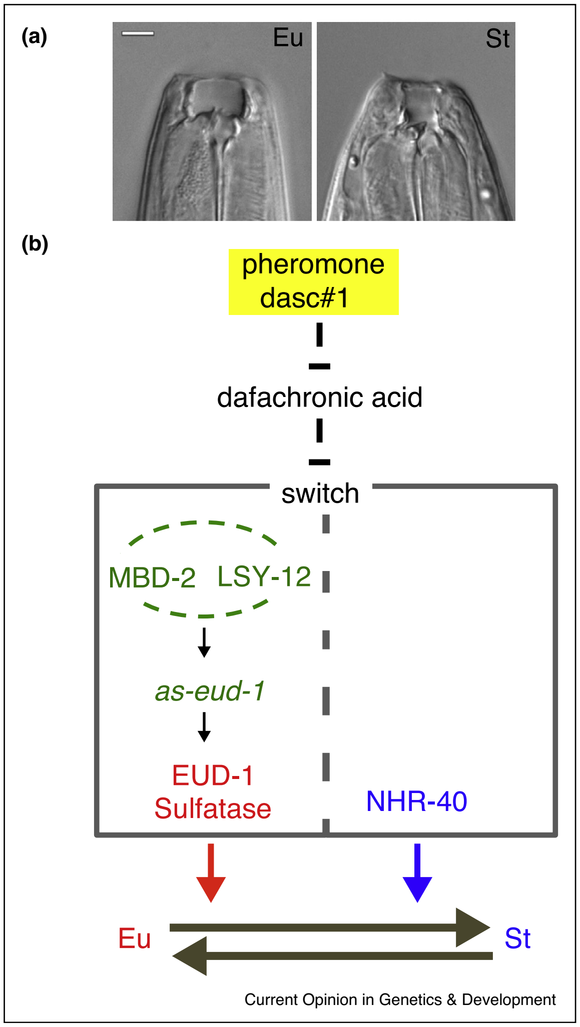
Figure 1



Current Opinion in Genetics & Development

The lifecycle of *C. elegans* and *P. pacficus* shows properties that facilitate the analysis of environmental effects on the organism. Both species are self-fertilizing hermaphrodites that result in isogenic lines. Adult hermaphrodites lay eggs, which develop into first stage juveniles. If sufficient food is around, juveniles develop directly through four larval stages before becoming adult. Dietary simplicity allows grow of both nematodes on agar plates with *Escherichia coli* bacteria as only food source. Under harsh conditions, second stage juveniles can form arrested alternative third stage larvae called 'dauer larvae' that are long-lived representing the survival and dispersal stage of many nematodes.

Figure 2



Current Opinion in Genetics & Development

P. pacificus mouth-form plasticity.
(a) The mouth dimorphism. Eurystomatous (Eu) animals (left) have a wide buccal cavity with two teeth, whereas stenostomatous (St) animals (right) have a narrow buccal cavity with a single dorsal tooth. Scale bars, 5 μm **(b)** Genetic control of feeding plasticity. The sulfatase-encoding gene *eud-1* and the nuclear-hormone-receptor *nhr-40* act as developmental switches controlling the Eu and St morph, respectively. Epigenetic regulation of the *eud-1* switch involves histone modifications and the methyl binding protein MBD-2 and the histone acetyltransferase *lsy-12* acting through an antisense message at the *eud-1* locus (as-*eud-1*) (all in green). Upstream of the switch, small molecule signaling involves pheromone and hormone regulation, which is not subject of this review.

phenotypes depending on environmental conditions and represents a basic principle of developmental and evolving systems. Recently, several studies have started to investigate the developmental regulation of plasticity at the molecular level and plasticity research is becoming an important branch of contemporary developmental biology [16–18]. In contrast, mainstream evolutionary theory has so far taken little notice of plasticity and often considered it to represent noise [8,10]. One major reason for this might be the inherent difficulty to distinguish between phenotypic variation caused by plasticity (and thus the environment) and phenotypic variation resulting from genetic polymorphisms. One group of organisms that can help to overcome this difficulty are self-fertilizing hermaphrodites, such as the nematodes *P. pacificus* and *C. elegans*. These species can be cultured as isogenic lines (Figure 1), a method that results in the absence of genetic polymorphisms and thus allows unprecedented insight into the genetic and environmental control of plastic traits [12,13].

Feeding plasticity in *Pristionchus* is regulated by developmental switch genes

One promising system to study the interaction between genes and the environment in the regulation of plasticity is a feeding dimorphism in *P. pacificus* (Figure 2) [19]. *P. pacificus* and related nematodes can form two alternative and discrete mouth-forms: a narrow-mouthed 'stenostomatous' (St) and a wide-mouthed 'eurystomatous' (Eu) form (Figure 2a). There are no intermediates, and thus, St vs. Eu mouth-forms represent a polyphenism with strikingly different feeding properties. St animals with a single flint-like dorsal tooth are strict bacterial feeders, whereas Eu animals with a claw-like dorsal and a large subventral tooth can also predate