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Theodosius Dobzhansky (1900–1975): Microbiology in the Light of Evolution

Ulrich Kutschera and Rajnish Khanna

I-Cultiver, Inc., Manteca CA 95336 & Department of Plant Biology, Carnegie Institution, Stanford CA 94305 (USA)

E-mail: kutscherau@gmail.com ; rajnishkcal@gmail.com

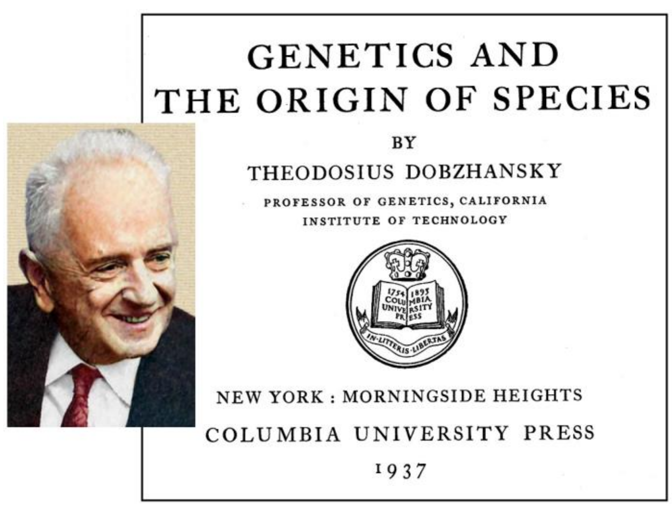
Abstract

Fifty years ago (1975), the eminent geneticist and evolutionary biologist Theodosius Dobzhansky died of cancer. He was one of the founders of the modern (synthetic) theory of biological evolution and well known for his experimental studies on fruit flies and other animals. With reference to our research on the interaction of microbes and plants (Methylobacteria-Sunflower etc.), we first present some new results; then, we document that Dobzhansky was one of the first to include microorganisms (bacteria, viruses) into his theoretical framework to explain the mechanisms of evolutionary change in variable populations of living organisms. In addition, we address the "evolutionary arms race" of bacteria-phage-interactions and argue that artificial environmental changes in agriculture cause novel selection pressures on soil microbes that may modify their evolution.

Keywords: *Bacteria, Dobzhansky, Evolution, Evolutionary theory, Microbes, Viruses*

Introduction

Three-hundred and fifty years ago (1674/76), the Dutch naturalist and entrepreneur Antonie van Leeuwenhoek (1632–1723), using custom-made microscopes, discovered protozoa and bacteria. As a result of his subsequent description of these "animalcules" (little animals), the scientific discipline of "Microbiology" was born [1]. In 1975, and hence three centuries after van Leeuwenhoek had discovered the first microorganisms, the Russian (Ukrainian) / American geneticist and evolutionary biologist Theodosius Dobzhansky (1900–1975) died of cancer (chronic lymphatic leukemia) that was diagnosed several years earlier (Fig. 1).


GENETICS AND
THE ORIGIN OF SPECIES
BY
THEODOSIUS DOBZHANSKY
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INSTITUTE OF TECHNOLOGY
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Fig. 1. The Russian (Ukrainian) / American evolutionary biologist Theodosius Dobzhansky (1900–1975) and the title page of his most important book Genetics and the Origin of Species (1937) (adapted from material of the Carnegie Institution, Stanford, CA, USA).

This eminent scientist is well known as one of the "Key-architects" of the Darwin-Wallace-based "Synthetic Theory of Biological Evolution" of the 1940s. In addition, he became popular by his 1973-statement:"Nothing in biology makes sense

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except in the light of evolution" [2]. In contrast to Ernst Mayr (1904–2005), and the other founders of the "Evolutionary Synthesis", who focused on animals and plants, Dobzhansky also discussed pro- and eukaryotic microbes, such as bacteria and unicellular algae [3]. Here, we summarize Dobzhansky's insights concerning microbial evolution from the perspective of our ongoing research on symbiotic plant-microbe-interactions [4], supplemented by unpublished observations (Fig. 2).

Evolution of microorganisms in the light of Dobzhansky

In his most famous book Genetics and the Origin of Species, Dobzhansky (1937) (Fig. 1) introduced the fact of evolution as follows: "Evolution as an historical process is established as thoroughly as science can establish a fact witnessed by no human eye. The mass of evidence bearing on this subject does not concern us in this book; we take it for granted. But the understanding of causes which may have brought about this evolution … is still in its infancy" [5]. Throughout the book, Dobzhansky referred to animals, such as fruit flies or lady beetles, and crop plants (bean, pea, maize, tobacco etc.). Under the headline: "Species in asexual organisms", bacteria and other microbes are only briefly mentioned twice. Quote-1.: "In very primitive forms, such as bacteria and some lower fungi, the sexual process has perhaps never taken place"; Quote-2.: "The subdivision of the mass of clones into the species *Bacterium coli, B. typhani,* and *B. enteridis* is purely a matter of taste; one might as well regard all of them as a single species" [5]. Hence, the "Synthetic Theory" was essentially deduced from observations and experiments carried out on macro-organisms (animals, plants).

Eighteen years later, Dobzhansky (1955) published a new book entitled Evolution, Genetics, and Man [6]. In the first chapter, he summarized facts about viruses and bacteria; accordingly, he fully incorporated the knowledge about microbes available at that time. In chapter 5, entitled: "Elementary Evolutionary Changes or Microevolution", Dobzhansky described the interaction of bacteriophages (viruses that attack/destroy bacteria) and "colon bacteria" (*Escherichia coli*), which "occur in the intestine tract of man and of other animals" [6].

In Figure 3 A we have reproduced the electron micrographs from Dobzhansky's 1955-book, showing the ca. 1 to 2 micrometer long *E.coli*-cells, surrounded by virus particles; in addition, we reproduce an image taken at higher magnification, documenting the structure of the tailed phages (Caudovirales) (Figure 3 B). A representative, classical "evolution-experiment using bacteria" is depicted in Figure 3 C. Colonies (i.e., clones) of *E. coli*-cells that serve as host organisms for the bacteriophages are visible as white spots growing on agar plates that contain nutrients and virus particles.

Fig. 2 Variable population of 6-day-old light-grown sunflower (*Helianthus annuus*) seedlings, raised in moist soil. Twenty years ago, on the cotyledons of these juvenile plants, methylobacteria were detected and characterized. Recently, we discovered that the meristematic region of the stem (arrow) is likewise inhabited by epiphytic microbes, as documented in the Inset (REM-Image) (unpublished Carnegie-data, Stanford, CA, USA).

Dobzhansky's interpretation of these evolutionary studies

During the early 1950s, the significance of these experimental results (Fig. 2) were a matter of debate. Dobzhansky argued that resistant mutants of E. coli occur in the cultures before they are exposed to the phages, which act as "intracellular parasites" that finally destroy their host cell. After a critical discussion of these findings, he concluded that this "microbiological evolution experiment" provides "vigorous proof of the validity of the hypothesis of spontaneous mutation", so that "resistant cells, which survive can be counted" [6]. (for more information on the scientific work of Dobzhansky, see [7], and the excellent recent article of Rudyshyn and Blume 2025 , ref. 8).

To the best of our knowledge, this was the first "textbook example" for rapid "bacterial evolution" in petri dishes. In other words: seventy years ago (1955), microbiology was integrated into evolutionary research using extant organisms. Today we know that, in natural ecosystems, bacteria-phage interactions are central to the evolution and diversity of these microbial communities. Moreover, experimental co-evolution has revealed that bacteria can rapidly develop resistance to phage attacks via de-novo mutations, and other mechanisms to defend themselves against infection by viruses. This "evolutionary-arms-race" is a thriving branch of research in microbial ecology [9] that can be traced back to the work of Theodosius Dobzhansky. In his 1955-book, Dobzhansky [6] also discussed the problem of the resistance of bacteria to antibiotics, with reference to "disease-creating microorganisms" in human and animal hosts; microbe-induced epidemics in human populations, such as the "Black Death in Europe 1347/48", and the genetic resistance of host organisms (mammals etc.) with respect to its immune system [6].

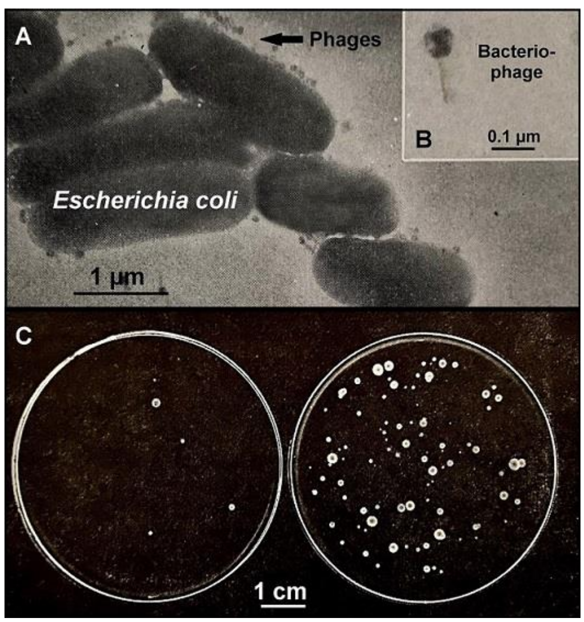

Fig. 3 Virus Particles (bacteriophages) attack colon bacteria (*Escherichia coli*) maintained in liquid culture. Free-living phages (arrow) attach to the surface of the *E. coli*-cells (A). The structure of these bacterial parasites is shown in the Inset (B). Two Petri dishes containing colonies of *E. coli*-cells that grow on solid agar surfaces in the presence of bacteriophages are depicted in (C). The bacteria have acquired, via spontaneous mutations, a resistance to the phages (viruses). In the dish on the right side, the resistance of the microbes is ca. 20 times greater than that in the left sample (adapted from Dobzhansky 1955, ref. 6).

Although Dobzhansky [5, 6] mentioned pea (*Pisum sativum*) plants and other members of the Leguminosae (*Vicia faba* etc.) in the context of Mendel's laws of heredity, he ignored the topic of symbiosis. Hence, the role of soil-bacteria (Rhizobia) with respect to the formation of root nodules and nitrogen fixation was not mentioned in the work of Theodosius Dobzhansky. Our mentor at the Carnegie Institution at Stanford University, the late Winslow R. Briggs (1928–2019), discovered in 2015 that rhizobia are "activated" by blue light so that the efficiency of nitrogen fixation in the symbiotic root nodules of pea (and bean) plants is enhanced (R. Bogomolni, pers. comm.). Figure 4 shows a Carnegie field at Stanford, where fava beans were grown to test the effect of soil microbes (activated vs. control) on seed yield. Hence, research on plant-microbe-interactions may be of considerable economic significance.

Agriculture and natural selection in the wild

Another aspect rarely considered in the context of rapid evolution of bacterial populations (Fig. 3) is the influence of human activities on selection pressure, and hence organismic adaptation, via artificial changes in the environment. For example, crop cultivation involves agricultural inputs, such as fertilizers containing macro- and micronutrients, which is usually accompanied by increased leaf photosynthesis and root exudates enriched in carbohydrates to recruit and enhance the density of beneficial microbes [10]. Although these influences are recent events, relative to the “big time scale” of biological evolution [2], the impact of agriculture on shaping microbial soil communities via natural selection is substantial (Fig. 4). Advances in modern biotechnology, including gene editing and next-generation sequencing, targeted manipulation of genomes etc. , may enable desired “plant-growth-promoting” bacterial taxa to gain an advantage over their ”natural” (wild-type) microbial competitors.

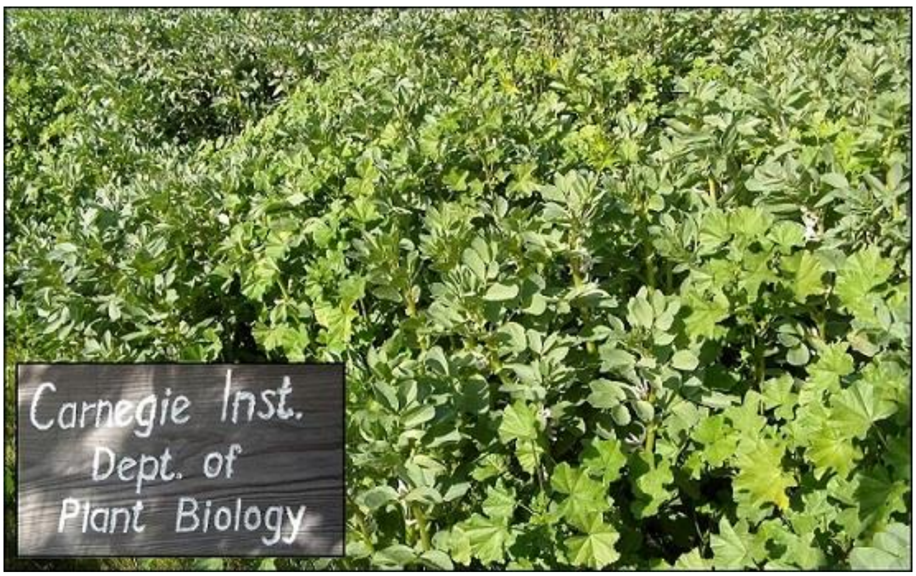

Fig. 4 Population of Fava Beans (*Vicia faba*) grown in 2018 on the field of the Carnegie Institution, Department of Plant Biology, Stanford University, CA, USA (project W.R. Briggs). The goal was to elucidate the effect of symbiotic soil microbes (*Rhizobium leguminosarum*), added to the seeds before planting, on crop yield. Such agricultural fields are artificially altered (non-natural) areas with respect to microbial ecology and evolution (photo by U. Kutschera).

Conclusions

This article is based on our ongoing experimental work on symbiotic plant-microbe-interactions, using crop species such as sunflower (Fig. 2), pea, bean and other seed plants. We conclude that Theodosius Dobzhansky (Fig. 1) may be viewed as one of the founders of the research area we call “microbial ecology & evolution”, because the other “architects“ of our modern theory of biological evolution entirely focused on “higher organisms” (animals, plants). In this context, we argue that agricultural practices, such as adding fertilizers to the soul etc., exert new selection pressures on bacterial populations, and hence artificially alters their natural environment, and likely their phylogenetic development (Fig. 4). It should be stressed that these attempts of scientists to “manipulate” microbial evolution [10] occurs within the theoretical framework that Dobzhansky provided seven decades ago via his integration of studies on bacteria, cultivated on agar plates (Fig. 3), into the emerging scientific discipline of evolutionary biology.

Acknowledgement

This article is dedicated to our former mentor and friend Prof. Winslow R. Briggs (1928 –2019), former Director of the Carnegie Institution-Dept. of Plant Biology at Stanford University, CA 94305-USA, an active researcher in this Institution until his death.

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