From Senecio to Epigenetics
Commentary on Jochen Bockemühl: Eine neue Sicht der Vererbungserscheinungen

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Goethe's archetype, his idea of the plant remains to this day an invisible entity, and thus a scientific absurdity. But its implications for genetics that Jochen Bockemühl carefully worked out phenomenologically at the end of the 1960s are intensively researched today. Common groundsel (*Senecio vulgaris*) is an autogamous plant, i.e. the parent plant produces offspring that phenomenologically can hardly be distinguished from one another if they are sown at the same time and under the same conditions. But not unexpectedly, morphologically there are many clearly distinguishable types. Such an outcome must arise from self-pollination.

According to Bockemühl, the differences can be understood if the formative potential of the various types is followed through the course of the seasons. Through monthly sowings, formative tendencies become visible which at other times are also shown by other types. For example, the shape of type A in April can hardly be distinguished from that of type B in July. Bockemühl argued that the types fix various formative tendencies and pass them on to their offspring. From this perspective, inheritance is not the cause of the shapes that arise but rather a result of them. Inheritance does not enable diversity but instead restricts it. As his writings show, Goethe arrived at a similar conclusion, only by other routes.

At the same time as the experiments with groundsel were being carried out, genetics appeared to have answered all its pertinent questions. The central dogma formulated by Watson and Crick was widely accepted. With the formula DNA → RNA → protein, it stated that in cells of all living organisms, information flows in only one direction, i.e. from the gene pool in the nucleus to the proteins in the cytoplasm. According to this interpretation, mutations and thus variations in the DNA can arise only by accident, for example by cosmic radiation or by errors in replication. In addition, the genetic code, the translation instructions by which the sequence of RNA base triplets is transmitted into the sequence of amino acids in protein, was meticulously decoded. The language of genes seemed to be understood.

In recent years the central dogma has collapsed. At each point in the formula, non-random changes are possible and happen constantly in the context of the organism and its surroundings. The genome projects have shown that what was once regarded as junk DNA sequences contain very many transposable elements (TE) (*Bauer*, 2008). Under 'stress', or one could also say in a changing external medium, they become activated, jump to other places in the genome and modify the activity of nearby genes.

The ENCODE project has shown that millions of micro-RNAs are read off which have regulatory functions (*ENCODE Project Consortium* 2004, 2012). Many of these RNAs are activated only in particular situations, for example under stress conditions, and can be inherited to the next generation. As a result, offspring are stressed even without any outer stressors. Comparable regulation of gene expression is also possible through methylation processes of DNA or acetylation events in the histones (*Felsenfeld* 2014). Histones are proteins on which the DNA is rolled up in the chromosomes. Both chemical modifications influence the three dimensional structure of the chromosomes. Methylation processes suppress the transcription of gene sequences, whereas acetylation processes facilitate them. Both situations are initiated by particular inner conditions, i.c. in the course of cell differentiation, and outer environmental circumstances, and can likewise be passed on to the next generation. Finally, with the discovery of molecular chaperones, it has become clear that at the third position in the central dogma, protein, organisms (yeasts, plants and animals) ensure their successful adaptation in evolution (*Buchner* 2002, *Shorter* and *Lindquist* 2008). Chaperones secure the correct folding of newly synthesised proteins. Furthermore, they can even keep in their original structure proteins that have been altered by mutations, i.e. make 'faults' seem faultless. Under extreme environmental conditions, organisms can immediately react with new protein structures, thus eventually ensuring the organism's survival (*Wirz* 2008).

Although the significance of these non-accidental effects for evolution are currently hotly debated, and evidencing them is not always easy, it is clear that the most important novelties in evolution happen not through gene mutations in the classical sense, but through refinement of the regulation of gene expression. In agreement with Bockemühl's interpretation, this is achieved by the organisms themselves during their development in their habitats.

Literatur / References

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