Biological Robustness and Fragility

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Robustness and fragility are ubiquitously observed features of biological systems. These two characteristics are useful for gaining a deeper understanding of the connection that exists between biological systems and their environments. Therefore, it is necessary to completely comprehend the concepts of robustness and fragility, as well as their intrinsic relationships.

Biological robustness is a property that allows a system to maintain its functions despite external and internal perturbations [1]. It is frequently interpreted to mean remaining unchanged in the face of stimuli or mutations, but in fact, robustness allows changes in the structure and components of the system owing to perturbations, but specific functions are maintained. For example, industrial microorganisms such as yeast and single-celled algae can cope with harsh industrial environments and have comparable production properties to normal environments. They maintain their original state despite being constantly disturbed in an industrial setting.

Biological robustness is an essential part of survival, since it makes it possible for organisms to endure or bounce back from perturbations that would otherwise be fatal. For instance, when the living conditions of Asian elephants deteriorate, they are forced to adapt to the current conditions in order to survive, and if they do not have biological robustness, they will be dangerously close to dying. Consequently, robustness is an essential component in the maintenance of the normal life of organisms.

In contrast to robustness, biological fragility describes the susceptibility of an organism or system to fail in response to disturbances or stresses originating from the outside environment. Extreme fragility can sometimes bring about catastrophic outcomes. For instance, over the past few decades, increased global warming has had a significant impact on the forest ecosystems that are found in the Yangtze River Basin. Under such circumstances, if these ecosystems continue to be disrupted by human activities, it is possible that they will fail to recover and eventually collapse. As a result, in order to prevent the system from being destroyed, we have to take measures to avoid fragility.

The avoidance of fragility can primarily be accomplished in two ways. Firstly, it is important to understand the causes that make an organism or system break down. Measures are then taken to prevent these interferences so that the probability of the system being attacked is greatly reduced. Another strategy is to provide robustness to the system, including System controls, modularity and so on [1].

There are intrinsic trade-offs between biological robustness and fragility. Enhanced robustness against certain perturbations has to be balanced by extreme fragility elsewhere. This robust yet fragile nature, predicted by the highly optimized tolerance (HOT) theory, is a fundamental property of the system that has been optimally designed or has evolved to cope with perturbations [2]. The trade-offs between robustness and fragility can be intuitively understood by using the plane example. Unlike modern commercial planes, the Wright brothers' plane is not resistant to atmospheric disturbances. However, they are extremely vulnerable to unusual perturbations, such as total power failure, because their flight-control system is entirely dependent on electricity. The Wright brothers' plane, on the other hand, is unaffected by this type of failure because it does not use electrical controls in the first place. Although they might seem simple, it is critical to recognize these trade-offs because diseases are frequently manifestations of fragility.

In conclusion, both robustness and fragility are prominent characteristics of biological systems. Biological robustness is a property that allows a system to maintain its functions despite external and internal perturbations, whereas biological fragility describes the susceptibility of an organism or system to fail in response to disturbances or stresses originating from the outside environment. Numerous organisms rely on their biological robustness to ensure their continued existence, and the results of biological fragility can have devastating effects. In addition, it is possible to circumvent fragility by examining the factors that contribute to it and providing robustness to systems. Last but not least, understanding the inherent trade-offs that exist between them helps us better comprehend systems.

References

[1] Kitano, H. Biological robustness. Nat Rev Genet 5, 826–837 (2004)
[2] Carlson, J. M. & Doyle, J. Complexity and robustness. Proc. Natl Acad. Sci. USA 99 (Suppl 1), 2538–2545 (2002)