# Definition

Biological robustness refers to the ability of a biological system to retain certain characteristics (certain phenotypes or system functionalities) under disturbances (genetic mutations/recombination, environmental changes, stochasticity). Biological fragility describes the contrary, i.e., the inability of a system to keep certain traits unchanged.

# Examples

Robustness: in Mendelian traits, a dominant gene can remain expressed, despite of genotypic change (i.e., if genotype AA changed to Aa due to a mutation or recombination during sexual reproduction, the phenotype is unchanged.).

Fragility: human fingerprints can differ between genetically identical individuals (e.g. twins), simply due to stochasticity.

# Importance of Robustness

In the short run, robustness prevents organisms from being imminently affected by small, short-term external changes, allowing them to keep the beneficial traits that are adapted to the general environment. Likewise, stochastic deleterious genetic mutations that threat key functionalities (such as early development, reproduction, etc.) will be blocked by maintaining a mutational robustness.

In the long run, robustness allows genetic variation to accumulate without changing the genotype, and when external changes eventually pass the threshold for the robustness, these variations will be released and lead to new phenotypes. While many of these new phenotypes can be less fit, some of them could happen to have a higher fitness (compared to the ancestral phenotype) and thus cause evolution towards these directions.

# Consequences of Fragility

Being biologically fragile, as opposed to robust, means an organism will be sensitive to genetic and environmental changes.

In terms of environmental disturbances, such as temperature or nutrient availability changes, being fragile is usually deleterious. If an organism’s key functionalities (e.g. nutrient uptake, processing, etc.) is easily affected by external conditions, then likely the organism will have a lower fitness. Thus, robustness (especially those of key traits, and in frequently changing environments) can be favored by selection. Though, on the other hand, being highly robust can cause slower adaptation to the new environment in the short term, theoretically.

In terms of genetic mutations and stochasticity, being fragile doesn’t necessarily infers a disadvantage. Theoretically, being less mutationally robust means mutations will more likely be expressed and thus be under higher selection pressure. The pace of evolution, then, should be faster in biologically fragile organisms, and indeed many studies seem to have observed a lower robustness in viruses (Rihn et al., 2013; Sanjuán R., 2010), who constantly mutate and evolve to avoid tracking by the immune system. Though, on the other hand, several experiments provided evidence that robustness can promote evolvability (the ability to access diverse heritable phenotypes) (Masel et al., 2010; Wagner A., 2008). This, to some degrees, can be explained by the afore-mentioned mechanism of genetic variation accumulation (also named evolutionary capacitance). Other studies (that utilizes mathematical modeling) hypothesizes that the relationship between robustness and evolvability is affected by parameters like population size, mutation rate and fitness landscape (Draghi et al., 2010).

# Maintenance of Robustness

Genetic fragility is commonly avoided via redundancy and distributed robustness. Redundancy, as the name suggests, refers to the presence of duplicate genes that share the same functionality. Thus, if one or more of the genes mutate or become lost, the rest of the genes are still preserved to maintain that shared functionality. Distributed robustness, on the other hand, means multiple different methods exist to achieve the same functionality. For instance, several key metabolites can be produced through different metabolic pathways.

From a molecular biology perspective, genetic robustness can be promoted via mechanisms that make the genetic mutations non-effective (neutral). For instance, most amino acids are encoded by several different codons, so if one of nucleotides was replaced by another due to a point mutation, that codon might still produce the same amino acid after translation (e.g., Phenylalanine is encoded by UUU and UUC, so if the third U turned to C by a mutation, the codon still translates to Phe). Another example would be the ability of similar amino acid sequences to fold into almost identical protein structures.

Similar concepts also apply to the maintenance of environmental robustness, e.g. production of important compounds persists under stressful conditions as multiple production mechanisms exist; transcription and translation of vital genes are overseen and double-checked via multiple methods, to ensure their proper expression, etc. The chemical properties of key compounds that allow them to function as expected in a wide range of chemical conditions can be another example.

# References (APA format)

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