# **Natural Selection**

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| **Advantages:** | **Considerations:** |
| * Theory suggests that a population of organisms can change naturally over time as a result of individuals with certain heritable traits (and therefore a greater survivability) having more offspring than other individuals 3 * The natural, evolutionary process that consistently results in adaptation and is believed to have established much of the diversity that exists on Earth 2 * Tends to result in organisms with adaptations related to survival, as opposed to increased yield or other human-centric goals. Those individuals that high survivability and reproductive abilities contribute the highest number of offspring to the next generation, creating potential for those traits to become more common 3 * Crops adapt to perform well under the specific climatic and field conditions associated with their location 1 * It is almost impossible to find phenotypically or ecologically distinct populations that do not show genetic differentiation when compared with one another. 4 * Genes that are especially advantageous for survival will spread through the local population and likely migrate and spread into other populations. This process is different for neutral or negatives genes. 4 * Occurs naturally in wild settings and does not require human intervention 2 | * Doesn’t often result in “extreme” physical expression of traits given that they don’t provide an added benefit to survivability 2 * Natural sources of genetic variation affecting trait expression includes mutation and DNA recombination that is inherent to the DNA reproduction process 3 * Interactions between the individual and the environment determine whether the individual has greater “fitness” than the others, meaning it exhibits traits that increase its survivability instead of increasing its agricultural value 3 * There is no guarantee that genes that enhance survivability will be passed on through multiple generations to the point that it is expressed in a majority of offspring. This is especially true for recessive traits. If this does happen, it will likely require a significant amount of time 4 * All species have the potential to express specific genes differently, but that doesn’t mean they do. They may be adapted to survive in their current environment, and therefore do not require variation in their expressed genes to enhance survivability 4 * When a population of a species is moved to a new habitat, there is frequently simultaneous natural selection for many traits to adapt to new predators and competitors, and phenotypes tend to become “fixed” after this process, meaning they evolve at a much slower rate 4 |

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2. Conner, J.K. (2003). Artificial selection: a powerful tool for ecologists. *Ecology. (84)7:* 1650-1660.
3. Phillips, S.L. & Wolfe, M.S. (2005). Evolutionary plant breeding for low input systems. *Journal of Agricultural Science (143):* 245-254*.*
4. Antonovics, J. (1976). The Nature of Limits to Natural Selection. *Annals of the Missouri Botanical Garden. (63)2:* 224-247.

# **Selective Breeding**

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| **Advantages:** | **Considerations:** |
| * Domestication goals are driven by human culture and interests, including simplified harvesting techniques, greater crop yields, preferred cooking/eating qualities, improved storability, or more reliable germination 1 * Often focused on physical characteristics (phenotype) of the organism, such as taste, color, size, or texture, increasing the range of physical characteristics that exist within that specific plants genome 1, 3 * Often results in plants that look different than their wild relatives 2 * Has been used to domesticate plants for the past 10,000 years 1 * Has resulted in plant species with greater fitness that can succeed in various landscapes across the planet 1 * Has produced some plants that are easier to harvest and process than their wild relatives 1 * Creates multiple varieties of the same species, each with a specific difference 1 * Selective breeding is simpler conceptually and technologically than more newer breeding programs and technologies 3 * Able to selectively breed for most traits, although there may be multiple genes responsible for that specific trait 3 * Promotes phenotypic changes at a more rapid pace than natural selection/evolution 4 * Selective breeding is an important tool for industrialized food production processes 4 | * Breeding for a specific trait may reduce or redistribute the genetic diversity in the gene pool2, often referred to as a “domestication bottleneck” 4 * Requires a variable amount of time to have the trait displayed in a majority of offspring. Some plants can be domesticated rapidly (less than 20 years) or very slowly (over 1,000 years) 1, 2 * Has created plants with reduced abilities for natural seed dispersal, creating species that are dependent on humans for survival and propagation. Many domesticated plant varieties cannot survive in the wild without human interference 1 * Commonly referred to as a type of human-directed evolution, which affects the natural evolution of the species 3 * Expression of traits is often the result of multiple genetic markers. Selecting for one specific trait may affect multiple genetic markers, potentially affecting multiple traits 3 * Selective breeding often involves growing and maintaining specific plants in a greenhouse or laboratory, sometimes for long periods while controlling matches for multiple generations 3 * Expressing new traits does not necessarily result in a plant that is more adapted for survival 3 * Select for the “best” parent exhibiting the desired trait and breeding that parent multiple times to establish offspring exhibiting that same trait 4 * Reduces variability within genotypes (variety of phenotypes available within the individual plant) and among genotypes (variety of phenotypes available across the species) in pursuit of uniform crop species 4 |

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1. Purugganan, M.D. & Fuller, D. Q. (2009). The nature of selection during plant domestication. *Nature* *(457):* 843-848.
2. Gross, B.L. & Olsen, K.M. (2010). Genetic perspectives on crop domestication. *Trends in Plant Science. (15)9:* 529-537
3. Conner, J.K. (2003). Artificial selection: a powerful tool for ecologists. *Ecology. (84)7:* 1650-1660.
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# **Induced Mutations**

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| **Advantages:** | **Considerations:** |
| * Technology established in the 1950s and continues to be improved 1 * A majority of mutant varieties have been released since the 1990s 2 * Involves genetic changes that suddenly arise from the application of physical or chemical mutation agents (mutagens), which may produce relatively large effects on the phenotype and the expression of existing traits 2 * Can be used to create varieties with altered physical characteristics (seed size, seed color), higher yields, or disease resistance (leaf rust) 1 * Very successful in breeding ornamental and horticultural crops 1 * Can result in multiple mutate alleles with different degrees of trait modification 1 * In recent years, this technology has been used to identify and isolate genes and to study the structure and function of genes to help inform future crop improvement programs 2 * Can be used to establish dwarf and semi-dwarf mutants with reduced plant height 2 * Can be used to establish varietals that mature earlier than their wild relatives 2 * May result in increased yield by altering traits that affect yield, such as number of flowers and pods per plant 2 * Some mutants exhibit improved tolerance to stresses, including insect and disease resistance 2 * Originally, scientists were only able to assess how this technique affected the physical characteristics of the plant, but recent technological advances allow us to identify changes at the genetic level as well. | * There are multiple steps between effectively mutating DNA using a mutagen and an altered phenotype 1 * Introducing the same mutagen to different species will have different effects on the species traits 1 * Applying both physical and chemical mutagens can have combined effects on a plant species 1 * Mutations do not have to be induced by humans, they can occur naturally 1 * Most mutants varieties are developed by exposing the parent plant to physical mutation agents (mutagens) like X-rays and gamma rays 2 * Most of the varieties of crop plants that have undergone induced mutagenesis and been released to the public are seed-propagated species 2 * Increases in yield that are established using induced mutations are highly variable, ranging from marginal to substantially high 2 * Treatments for inducing mutation for a specific trait often result in altering several traits. Mutants usually show simultaneous changes in several places within the DNA sequence 2 * Mutant plants exhibiting a desired trait are often used as a parent plant during selective breeding programs 2 * Disease and insect resistance can be complete or partial, durable or non-durable, and only a small proportion of mutants exhibit this resistance in any type of practical way 2 * Site directed induced mutations allow scientists to make a specific change at a specific location within the DNA sequence, although randomly inducing mutations continues as one method 2 |

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1. Chopra, V.L. (2005). Mutagenesis: investigating the process and processing the outcome for crop improvement. *Current Science (89)*2: 353-359
2. Kharkwal M.C., Pandey R.N., Pawar S.E. (2004) Mutation Breeding for Crop Improvement. In: Jain H.K., Kharkwal M.C. (eds) Plant Breeding. Springer, Dordrecht

# **Genome Duplications**

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| **Advantages:** | **Considerations:** |
| * Dramatically increases the amount of genetic material available within the individual plant, which can increase diversity of traits that are exhibited or buffer the plant from any genetic mutations that occur naturally during the DNA replication process 1 * Many crop species and flowering plants already have multiple sets of chromosomes and are prone to this type of breeding/reproduction 2 * Polypoid plants often exhibit increased vigor and sometimes outperform their non-polyploid relatives 1 * Often produces plants with reduced fertility or sterility, allowing breeders to produce seedless varieties 1 * Can induce polyploidy on plants that don’t naturally exhibit it 1 * Can result in varietals that develop “extreme phenotypes” 3, which may be useful for selective breeding processes 1 * Plants develop larger cells to house the increased amount of genetic material, which may or may not cause larger plant size 1 * Polyploid plants tend to have lower growth rates, increased plant organ size (leaves, fruits, tubers), and flower later or over a longer period of time than related diploids 1 * Used widely in ornamental crop breeding given that it extends flower longevity, increases flower sizes, and deepens the flower color 1 * Many plants arose from ancestor species that experience natural polyploidization events hundreds of thousands of years ago 4 | * Polyploids do not always exhibit higher quality and/or yield, or these improvements occur in plant organs that aren’t of interest (e.g. large leaves but interested in developing large fruit) 1 * Each plant species responds differently to polyploidization, which is dependent on many different factors 1 * Reduced fertility and sterility can be difficult when the organs of interest are associated with the reproductive system (e.g. fruits, seeds, flowers) 1 * Induced polyploids do not always reach the breeder’s initial expectations for the commercially relevant traits and therefore don’t overcome their diploid relatives in production processes 1 * The costs of polyploid seeds can be much higher than seeds for non-polyploid/diploid relatives, resulting in greater costs for the farmer and a higher end-market price 1 * Many polyploids experience extensive and rapid genomic alterations, which might not always be for the best 4 * Survivorship of duplicated genes are different depending on the gene, although some genes are more prone to being retained by the plant 4 * Extensively rearranges genetic material in the entire plant genome, often exchanging material between plant genomes and losing genes over generations 4 * Some genomic changes have arisen immediately, while others occur within a few generations 4 * Sometimes results in genomic changes that effect the physical expressions of the plant, which may be beneficial or not for the natural selection process 4 |

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  2. Chopra, V.L. (2005). Mutagenesis: investigating the process and processing the outcome for crop improvement. *Current Science (89)*2: 353-359
  3. Van de Peer, Y., Maere, S., & Meyer, A. (2009). The evolutionary significance of ancient genome duplications. *Nat Rev Genet. 10*(10): 725-732.
  4. Adams, Keith L., & Wendel, J.F. (2005). Polyploidy and genome evolution in plants. *Current Opinion in Plant Biology. 8*(2): 135-141.

# **Gene Editing**

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| **Advantages:** | **Considerations:** |
| * Involves transferring DNA from one organism to another to allow the recipient to express traits normally associated with just the donor 2 * May reduce environmental impacts associated with farming. For examples, plants that have been modified for an increased yield may require less land to be farmed 1 * First genetically modified crops were planted in 1995 and the technology has continuously improved since then 2 * Transferring DNA like this does not happen naturally, greatly expanding what was possible through traditional breeding programs, including induced mutations and genome duplications 2 * Allows breeders to “turn off” the expression of undesirable genes, introduce new genes, enhance existing genes, intentionally affecting how traits are expressed by the plant 2 * Commercial applications have primarily been focused on creating crop varieties that exhibit herbicide tolerance and insect resistance to specific agents, although a wide variety of benefits are possible 2 * Planting genetically modified crop with insect resistance often reduces the need for pesticides, although that reduction is different depending on the crop species 2 * Can be used to enhance the nutritional value of crops, which can have significant positive impacts, especially in developing countries 2 * The change in DNA is done precisely – scientists have identified where exactly the DNA needs to be added, removed, or changed to affect the desired change in plant characteristics 2 | * Genetically modified species could be at a greater risk to become invasive considering that they are often bred to have a trait that enhances their success in specific ecosystems and environmental conditions 1 * Genetically modified varieties may cross breed with “wild” species or subspecies, creating new varieties which may exhibit the trait or potentially contaminating non-GMO varieties1 * Can result in reduced genetic diversity and genetic bottlenecks 1 * Some consumers are concerned about the lack of understanding about the various long-term effects and unintended consequences, environmental effects, and health risks 1, 2 * Genetically modified crops that continuously express resistance proteins (insect, virus, herbicide) may lead to increased resistance, which may result in new chemical pesticides or ultimately eliminate the original benefits of the modified plant species 1 * The term “genetic modification” does not represent a single technology. Each application has its own potential risks and benefits for different stakeholders 2 * Some seeds are built in with “terminator technology”, meaning that a gene has been inserted to prevent any seed saved after harvest from germinating, preventing the spread of genes from GMOs to wild relatives and requiring farmers to purchase new seeds each year 2 * Planting genetically modified crop with herbicide resistance often results in increased amount of herbicide applied pesticides 2 * Technology requires scientists to endure many years of trial and error to create an organism exhibiting the desired trait 2 |

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  2. Pretty, J. (2001). The rapid emergence of genetic modification in world agriculture: Contested risks and benefits. *Environmental Conservation.* *28(3)*, 248-262. doi:10.1017/S0376892901000261