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11. Inbreeding Depression in Cross Pollinated Crops

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Abstract:

Higher homozygosity is a consequence of inbreeding. Increased homozygosity in cross-pollinated species causes a decline in inbreeding or decreased productivity. The following are some signs of inbreeding depression: decreased plant vigor; smaller plants; decreased fertility; suppressed seed output; decreased pollen production; inferior seed quality; increased vulnerability to disease or insect damage; or poorer standability.

Keywords:

Inbreeding, Homozygosity, Low Productivity, Cross Pollination, Sterility

11.1 Introduction:

Asexual and cross-pollinated organisms are extremely heterozygous and typically exhibit a significant decline in vigour and fertility as a result of inbreeding. On the other hand, hybridization of unrelated strains usually results in higher vigour and fertility. When reproducing these species, these two factors are crucial. With these crops, the majority of the improved varieties make use of the phenomenon of hybrid vigour and are either synthetics or hybrids plus/or composites. As a result, we would go into further detail on these characteristics of asexual and cross-pollinated species.

11.2 Inbreeding:

Consanguineous mating, or inbreeding, is the mating of individuals who are related to one another through bloodline or descent. In high levels of inbreeding, such as sibling mating or brother-sister mating, the degree of inbreeding increases. Selfing results in the highest level of inbreeding possible. The primary outcome of inbreeding is a rise in homozygosity in the offspring, which is correlated with the level of inbreeding. Actually, the degree of homozygosity in the progeny provides a measure of the degree of inbreeding. For instance, each generation of selfing results in a 1/2 reduction in heterozygosity and a corresponding increase in the level of inbreeding. The degree of homozygosity in a generation is really correlated with the degree of inbreeding in that generation. An individual's inbreeding coefficient (F) indicates how much they have inbred. The likelihood that a person's two gene alleles came from a single allele of a common ancestor—that is, an ancestor who appeared in the lineage of both the person's paternal and maternal parents—is represented by the value of F for that particular person. A plant selfing from a random mating population produces an individual whose value of F is %, but the value of F for each individual in a random mating population is 0. Over several generations, F accumulates value.

11.3 Inbreeding Depression:

The term refers to the decline in fertility and vitality caused by inbreeding. Depending on the plant species in question, the level of inbreeding depression will vary. However, the relative fitness of the trait in question and the value of F are connected to the degree of inbreeding depression within a species. Characters that contribute little to fitness typically exhibit little to no inbreeding depression, but inbreeding depression is widespread in the case of such qualities that are crucial to fitness.

As evidence that variation for heritable fitness qualities happens within populations, both plants and animals exhibit the phenomena known as inbreeding depression, which is the decreased survival and fertility of offspring of related individuals. The distinction between outbreeders and inbreeders was first made by British naturalist Charles Darwin.

Outbreeders are plants with reproductive mechanisms that promote cross-pollination; these species typically exhibit inbreeding depression and tend to be intolerant of inbreeding, such as alfalfa and maize, while inbreeders are plants with reproductive mechanisms that promote self-pollination, which minimises inbreeding depression and tolerates many generations of inbreeding, such as wheat and Darwin observed that many plant species have evolved defence mechanisms against self-fertilization. Outcrossing is more common in nature than self-fertilization. Complex reproductive systems in plants encourage outcrossing.

11.4 History:

Humans have long recognized the symptoms of inbreeding depression. Considering the negative consequences of inbreeding, it might not come as a surprise. Historically, it has been forbidden for members of close families to marry each other in many societies. Hinduism is an extreme example of a society that forbids marriages between people who are related to each other, regardless of how distantly. However, it wasn't until inbreeding became a widespread technique in cattle breeding around 1700 A.D. that systematic observations on its effects started. Production increased significantly, but there was also a noticeable drop in fertility.

As a result, outcrossing the inbred lines eventually became necessary to boost fertility. In the book Cross and Self Fertilization in the Vegetable Kingdom, which was published in 1876, Darwin came to the conclusion that offspring resulting from self-fertilization were less robust than those resulting from outcrossing. The outcomes of his studies on self- and cross-fertilization in maize were also published by him; these are the first documented accounts of inbreeding depression in this crop. In 1908 and 1909, Shull and East independently published detailed and accurate malformations related to inbreeding in maize. Research on additional crop plants was then published. Inbreeding has been shown to have negative, frequently severe effects on cross-pollinated and asexually propagated plants.

11.5 Effects of Inbreeding:

As discussed in the following sections, inbreeding typically results in a general decline in vigour, reproductive capacity, or fertility, size of different plant parts, and yield.

- Lethal and Sublethal Alleles Appear: Recessive lethal (causing death), sublethal, and subvital (lowering survival and reproduction rate) traits emerge as a result of inbreeding. These traits include deficiencies in chlorophyll, seedlings without roots, flaws in the structure of flowers, etc. Plants with these traits typically disappear from the population.
- Diminished vigour: The population's vigour has generally decreased. Plants generally become smaller in all plant parts, which causes them to grow shorter and weaker.
- Reduction in Reproductive Ability: The population's capacity to procreate is rapidly declining. Many plant progenies, or lines, reproduce so poorly that they are unmaintainable. Few inbred lines possess sufficient fertility in most crops to be easily maintained and utilized in breeding programmes.
- Population Splitting into Distinct Lines: The population splits up quickly into lines that differ phenotypically. This is the outcome of multiple alleles randomly fixing in distinct lines due to an increase in homozygosity. As a result, the lines have different genotypes and phenotypes. The population's overall variance rises as a result of this.
- Rise in Homozygosity: After inbreeding, each line becomes progressively more homozygous. As a result, variation within a line diminishes quickly. The lines eventually become nearly uniform after 7 to 8 generations of selfing because they are getting close to complete homozygosity (>99% homozygosity). The lines are referred to as inbred lines or inbreds because they are nearly homozygous as a result of continuous inbreeding and are kept that way through close inbreeding, ideally by selfing.
- Yield Reduction: Inbreeding typically results in lower yields. Relative to open-pollinated varieties, sustainably maintained inbred lines yield significantly less. The most successful inbred lines of maize produce approximately 50% of the open-pollinated varieties from which they were derived. The yield is significantly reduced in lucerne and carrots, but in onions and many cucurbits it is very small.

11.6 Degrees of Inbreeding Depression:

Depending on the crop species, inbreeding depression can vary greatly in intensity, be non-existent, or be very high. The following categories can be used to classify the level of inbreeding depression seen in different plant species: (1) high, (2) moderate, (3) low, and (4) lack of depression caused by inbreeding.

- Depression Due to High Inbreeding: Numerous plant species exhibit extremely high inbreeding depression, such as carrot, lucerne, and others. Selfing produces a high percentage of plants that are deadly and do not live. After three or four generations of inbreeding, very few lines are still viable due to the significant loss of vigour and fertility. The lines that do make it typically have yields that are significantly lower than 25% of those of open-pollinated varieties.

- Moderate Inbreeding Depression: A number of crop species exhibit moderate inbreeding depression, including sorghum, bajra (P. glaucum), maize, and others. Although a significant percentage of lines can be sustained under self-pollination, many lethal and sublethal types can be found in the selfed progeny. Fertility has significantly decreased, and many lines reproduce so poorly that they become extinct. On the other hand, a significant number of inbred lines can be produced, producing as much as 50% of open-pollinated varieties. Compared to species exhibiting a high degree of inbreeding, these species exhibit comparatively easier production and maintenance of inbred lines.
- Low Inbreeding Depression: A number of crop plants, including rye, sunflower, onion, and numerous cucurbits, exhibit very little inbreeding depression. Furthermore, the percentage of plants created through inbreeding that exhibit fatal or subvital traits is quite low. A small amount of vigour and fertility are lost, and in rare cases, low fertility prevents a line from being sustained. Some inbred lines may yield as much as the open-pollinated varieties from which they were developed, and the yield reduction is negligible or nonexistent.
- Absence of Inbreeding Depression: Self-pollinated species exhibit heterosis but not inbreeding depression.

In cross-pollinated crops, the process of outcrossing permits the exchange of genetic material between various individuals, producing offspring with a varied genetic composition. This leads to an inbreeding depression in these crops. Numerous advantages, such as enhanced vigour, adaptability, and resilience to environmental stresses, may result from this genetic diversity.

Although inbreeding or self-fertilization within cross-pollinated crops is possible, agricultural practises generally discourage it because of the possible negative effects. Similar to what happens in self-pollinated crops, inbreeding in these crops can result in the expression of harmful recessive alleles, decreased fertility, and decreased overall fitness.

It's crucial to remember that outcrossing, which lessens the risk of inbreeding depression and preserves genetic diversity, is the main method of reproduction in cross-pollinated crops. In self-pollinated crops, where individuals mate primarily with themselves or closely related individuals, inbreeding depression is more relevant and frequently observed, increasing the likelihood of inbreeding and its detrimental effects.

11.7 Cross Pollinated Crops: Reasons for Inbreeding Depression

A. Self-fertilization within cross-pollinated crops: While cross-pollination is these crops' principal means of reproduction, self-fertilization can sporadically occur. This may occur when a plant collects pollen on its own as a result of environmental circumstances, pollinator scarcity, or flower structure. Compared to outbred individuals, self-fertile offspring are more likely to suffer from inbreeding depression.

B. Isolated populations: There may be less chances for outcrossing when cross-pollinated crops are grown in isolated or fractured populations. There is a greater chance of inbreeding if the population's available mating partners are closely related. As a result, there may be less genetic diversity and a higher chance of inbreeding depression.

C. Breeding procedures and selection: Breeders occasionally carry out deliberate controlled self-pollination or inbreeding to produce inbred lines for particular goals, like producing pure lines or parental lines for the production of hybrid seeds. Repeated self-pollination or inbreeding in these breeding programmes can result in the accumulation of undesirable recessive alleles and inbreeding depression.

D. Founder effects and genetic bottlenecks: A cross-pollinated crop population that is formed from a small number of individuals (called a founder population) or that experiences a significant decline in population size (called a genetic bottleneck) may be more susceptible to inbreeding depression due to the decreased genetic diversity. Recessive alleles that are harmful can express themselves and lead to high levels of homozygosity due to the limited initial genetic variation or reduced gene pool.

11.7.1 Some Other Things to Think About When It Comes to Inbreeding Depression in Cross-Pollinated Crops:

Depressive outbreeding: It's important to remember that outbreeding depression can also happen in cross-pollinated crops, despite inbreeding depression being the more frequently discussed phenomenon. When individuals from genetically distinct populations or varieties are crossed, a decrease in fitness or performance is known as outbreeding depression. Genetic incompatibilities or disruptions in coadapted gene complexes may result from a large genetic divergence between the populations. Although it is less common than inbreeding depression overall, outbreeding depression can still occur in specific situations.

Heterosis or hybrid vigour: This is the term for the phenomenon that cross-pollinated crops frequently display. It speaks of the traits or performance that hybrid offspring exhibit that are better than those of their parents. Combining advantageous and complimentary features from genetically different parents leads to heterosis. Because hybrids can have superior yield, disease resistance, and other desirable traits, commercial agriculture frequently uses hybrids' increased vigour and productivity.

Genetic drift and gene flow: In cross-pollinated crops, gene flow is the transfer of genetic material by pollen from one population or variety to another. Gene flow can mitigate the detrimental effects of inbreeding depression and aid in the preservation of genetic diversity. However, random variations in gene frequencies within a population are known as genetic drift, and they can also happen. Small or isolated populations are more vulnerable to genetic drift, which can result in a loss of genetic diversity and a higher chance of inbreeding depression.

Breeding techniques: To reduce the chance of inbreeding depression and optimize the advantages of genetic diversity in cross-pollinated crops, plant breeders employ a variety of techniques. These tactics include conducting frequent hybridizations to introduce new genetic material, keeping large and diverse breeding populations, using advanced breeding techniques like marker-assisted selection or genomic selection to maximize genetic diversity and performance, and using selective breeding to promote desirable traits while avoiding excessive inbreeding.

11.8 Differential Response to Inbreeding:

High levels of heterozygosity and a high concentration of fatal, subvital, and other unfavourable recessive genes that have little immediate benefit to the species are found in cross-pollinated species. The genetic load of the species is the result of the combined effects of these unfavourable alleles. Because the dominant alleles of recessive alleles mask their negative effects, the recessive alleles remain in the population. As a result, the population develops a genetic organisation that favours heterozygosity, and homozygosity has negative consequences. Self-fertilized species, on the other hand, are homozygous by nature, meaning that unfavourable recessive genes become homozygous and disappear from the population.

These species would favour gene combinations that, in the homozygous state, exhibit no deleterious effects. However, depending on the particular gene combinations involved, these combinations may exhibit heterosis upon outcrossing. On the other hand, heterozygosity is the default state in cross-fertilized species. As a result, gene combinations that in a homozygous state would be harmful are not selected against and remain in the population. Such species would therefore exhibit inbreeding depression. The level of self-fertilization that takes place in the species' natural populations would primarily dictate the degree of inbreeding depression in these animals.

Cross-fertilized species, such as maize (*Zea mays*), exhibit moderate inbreeding depression and up to 10% self-pollination. Alfalfa (*M. sativa*) is one crop that exhibits extremely severe inbreeding depression due to very little inbreeding. Due to inbreeding, cross-fertilized species that are typically cultivated in extremely small populations, like cucurbits, would exhibit some homozygosity. These species would therefore exhibit little to no inbreeding depression.

11.9 References:

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