Course Name: Basics of Crop Breeding and Plant Biotechnology

Professor Name: Dr. Joydeep Banerjee

Department Name: Agricultural and Food Engineering

Institute Name: Indian Institute of Technology Kharagpur

Week: 03

Lecture-15: Heterosis and Inbreeding Depression

Hello everybody. Welcome to the SWAYAM NPTEL course on Basics of Crop Breeding and Plant Biotechnology i.e. Principles of Conventional Plant Breeding. We will be discussing on lecture 15 that will be on Heterosis and Inbreeding Depression. These are the following concepts which will be covered in this particular part. First one is heterosis, what is heterosis? we will be discussing. Then various nomenclatures will be discussed, different terms of heterosis, how different scientist explain heterosis in different way.

Then, what are the implications of heterosis will be discussed? Then we will discuss, the inbreeding depression. Then different effects of inbreeding will be discussed, and various degree of inbreeding depression will be discussed later on. In different crops, different degree of inbreeding depressions is observed.

Then finally, we will discuss the genetic basis of heterosis and inbreeding depression. Means heterosis and inbreeding depression, those are the outcome in F_1 or in subsequent generations, but what may be the basis, genetic reason behind it, we will be discussing through the genetic basis part. So let us start our discussion. First, we will be discussing heterosis.

First of all, heterosis is the superiority of F_1 hybrids in one or more characters, over its parents. Suppose, two parents have been crossed and we got a F_1, F_1 hybrid. So, in that F_1 hybrid maybe we may consider the F_1 for a particular trait. It may be fruit size, may be in one parent the fruit size was smaller, in another parent fruit size was little bit bigger but, once we got the F_1 the fruit size is bigger than both the parents. So, in this way, we can consider the superiority for a particular character or we can consider the superiority of F_1 for a number of characters, over its parents through heterosis. So, we will be discussing these things once again later on.

Then heterosis is also termed as hybrid vigor. In hybrid condition the significant growth is observed over there where, the offspring of the two different parents exhibit traits that are superior to those of the either parent. Third one is it, occurs because the combination of the genes from two different parents can lead to complementary and beneficial interactions. Because, different genes are coming from two parents and they can show some complementary action means, one allele of coming from one parent can complement another allele coming from a different parent, and some interactions might be involved over there also. So now we will be discussing different types of heterosis.

First of all, average heterosis. Suppose, a plant is having small a small a genotype and it is giving 10 quintals/hectare yield. While this is being crossed with another plant i.e. having capital A capital A genotype and it is producing 15 quintals/hectare yield. In F_1 by crossing these two plants, we are supposed to get capital A small a and here we are getting 13 quintals/hectare yield. The yield in F_1 is 13 quintals/hectare.

So if you compare the average performance of the two parents, what will be (10 + 15)/2 = 25/2 = 12.5. The average performance is 12.5 quintals/hectare, and in F_1 we are getting more than that 13 quintals/hectare. So, these things will be called as average heterosis means, in F_1 we are getting the value which is superior to the average performance of both the parents.

Next one is heterobeltiosis. In heterobeltiosis, this is the superiority of F_1, over both the parents. Like if you just consider, the previous two plants maybe this one was having 10 quintals/hectare yield while, this one was having 15 quintals/hectare yield. Ok! We got F_1. In F_1 we are getting 20 quintals/hectare yield.

This is will be termed as heterobeltiosis means, superiority of F_1 over both of its parents, ok, it is superior to both of the parents. Third one, is economic heterosis i.e. very important. So suppose we have crossed two plants, like similar way one was having this, another one parent was this, having 15 quintals/hectare we got F_1 and F_1 is showing 20 quintals/ hectare, like earlier this is heterobeltiosis indeed. But suppose two common rice varieties have been crossed over here. Ok! One is maybe variety X, another is variety Y.

So we got the F_1 having 20 quintals/hectare yield, but in our hand in the market another variety is available, maybe variety Z i.e. available in the market, and its yield is 22 quintals/hectare. This is already available in this in the market. So, whatever we observe in F_1, that will not be accepted by the farmers easily because they have already got another variety the yield of that variety is better. So, they will go for this one. So in this way we are not getting economic heterosis.

So we can term the heterosis as economic heterosis, if the performance of F_1 exceeds the performance of the already available varieties in the market, ok, means if it is 25 or something i.e. more than 22 quintals/hectare, then we can tell it as economic heterosis, ok, if it is more than 22, because the available performance in the market is 22 quintals/hectare. So, this one is the economic heterosis. Fourth one is negative heterosis. So i.e. also very important. In most of the cases, we tell that heterosis is the superiority of the F_1 over both of its parents.

So naturally this thing is considered as heterosis, but what is negative heterosis? Negative heterosis is the inferiority of F_1, over both of its parents and in sometimes this inferiority might be helpful for the plant breeders, for the farmers also. Let us assume, we have one tomato variety, ok, i.e. means, the flowering, the time of flowering in this variety is it basically, flowers maybe 45 days after sowing. Ok! While we have another parent that start flowering at 60 days after sowing, or transplanting whatever. So, suppose a cross has been made between these two parents, we got F_1, that flowers in 35 to 40 days. If you carefully see here the flowering time is lesser compared to parent 1 as well as parent 2 it is lesser compared to both the parents.

So this is the negative heterosis. For certain traits negative heterosis is beneficial, like for the flowering time in a particular plant the maturity time in a particular crop. Ok! Maybe the availability of some anti-nutritional factor over there also negative heterosis is beneficial. So, this is negative heterosis. Now we will discuss about certain facts associated with heterosis means, how a particular F_1 could be treated as heterotic or complete dominance is there or partial dominance is there or no dominance is there.

So with this small example, we will discuss these things means, this different scenarios may be there, based on the interaction of different alleles or based on the interactions of different genes available within the two parents and the F_1. So, suppose we have a particular parent P_1 it is making 8 quintals/hectare yield. Ok! This rice variety suppose it is a rice variety and it is making 8 quintals/hectare yield while, we have another rice variety i.e. making i.e. making 12 quintals/hectare yield. So, these two plants have been crossed to make F_1. So, in F_1 we may get different types of yield, and based on that we can tell whether it is heterotic or whether complete dominance is there whether, partial dominance is there or no dominance is there.

So, first of all, as we know the yield data or any specific data between plant 1 and plant 2 we can make the average performance. So, let us see, what will be the average performance? Average performance will be 8 + 12, (8 + 12) /2 quintals/hectare, i.e. 20/2 = 10 quintals/hectare i.e. the average performance. Now, if the value of F_1 become less than 8 quintals/hectare, if the value of F_1 becomes less than 8 quintals/hectare, what will be the scenario? It will be heterosis and in negative direction. So, we can tell it as negative heterosis.

For yield perspective 8 quintals/hectare is not at all good, but if we consider about the maturity time, the flowering time, on those cases the negative heterosis will be highly beneficial for the plant breeders for the farmers. Ok! So, these are just an arbitrary value to explain whether, heterosis will be there or complete dominance will be there, those things. So, if it is less than 8 then we can see heterosis in negative direction. If the value of F_1 is just 8 quintals/hectare, what will be the scenario? So, if you see, if you assume, this as small a small a and if you assume this as capital A capital A, F_1 will be capital A small a and if capital A small a is showing similar phenotype like this one, or it is showing similar phenotype like this one then, we can say as complete dominance. In complete dominance condition, what is observed? A particular allele will show its function means capital A capital A will be equivalent to capital A small a.

So, capital A allele is completely dominant over small a allele or if small a small a is equivalent to capital A small a then we can tell small a allele is completely dominant over the capital A allele. Ok! So, capital A small a, those are just different forms of a gene, this is just for your understanding means, if the parent 1 its value is equal to the F_1 value then, we can tell that complete dominance is available. Now, if the value of F_1, is the value of F_1, become more than 8 quintals/hectare, but less than 10 quintals/hectare. Ok! It is more than 1 parent, but it is less than the average value then, we can tell it as partial dominance means, it is towards the particular direction, it is towards the small a allele, right? So, we can tell it as partial dominance, the small a allele is showing partial dominance over capital A allele.

Now, if the value of F_1 becomes equals to just the average value, what we got average value, if it is means, if it equals to the average performance then, we can tell as no dominance means, none of this allele are showing dominance over another one. Ok! So, no dominance scenario is there, just the average performance we are getting. Similarly, if the value of F_1 becomes more than 10 quintals/hectare, but less than 12 quintals/hectare then, it will be again partial dominance. So, here the capital A allele its value is more means, towards that side in the heterozygote condition we are getting the result. Ok! So, partial dominance we can see over here, if the value of F_1 becomes equals to 12 quintals /hectare, what will be the scenario, we can tell it as complete dominance because this is similar to the performance of P_2.

So, we can tell it as complete dominance and if the value of F_1 exceeds 12 quintal /hectare then it will be again heterosis. So, I am just telling it once again, if the value is lesser than the poor parent or inferior parent or greater than the better parent then, we can tell it as heterosis. If it is equal to the mid parental value or average performance we can tell as no dominance is there. If it is similar to a particular parent, then we can tell it as complete dominance and if in rest of the cases we can see partial dominance if it lies between the performance of a particular plant, particular parent and the average performance if it lies in between then we can tell as partial dominance.

Now what are the different features of heterosis will be discussed? First of all, superiority over parents. So, in heterosis mostly we can see the performance of F_1 is superior over both of the parents. Next one confined to F_1 in most of the cases, the heterosis is confined to F_1, just if you consider that we have made cross between capital A capital A and small a small a. In F_1 we will get capital A small a means, most of the genes will be in heterozygote conditions and we can see heterosis. If we go to F_2 onwards, then again segregation will be started, we will see capital A capital A, capital A small a, small a those type of segregations will be available. So, we may not get the enough heterosis.

So, heterosis is mostly confined to F_1. Next one genetic control means, what type of genes are involved for this particular trait, and what we are considering for heterosis estimation, i.e. very important point. What type of interactions are available between those genes? It may show some dominance effect, it may show some epistatic effect. So, based on that different kinds of heterosis could be observed. Next one effect of heterozygosity means, if heterozygous is superior to both of the homozygous then we can see heterosis otherwise, we may not see sufficient heterosis, right, means, the heterozygous should be superior otherwise how our F_1 will be better.

Next one is reproducible. If we identify some suitable plants means, if we identify suitable parents, and if we see heterosis over there in F_1 generation then that things can be reproduced in case of self-pollinated crops, as well as in case of cross-pollinated crop if we can identify some suitable inbred lines, and we may cross among them to get the F_1 or F_1 hybrid there also we can see heterosis. So, it could be reproducible the similar inbred lines could be crossed again so that the F_1 will outperform both the parents.

Now we will be discussing different implications of heterosis. First of all, increase yield as the global population is increasing enormously. So, we must have to plan in such a way so that our food production could be enhanced. So, our target for most of the breeding applications, most of the breeding strategies would be increasing the yield and in case of heterosis also in most of the food crops like rice, wheat, maize, different food crops, different fruits, different vegetables we can see increase yield. So, i.e. one of the major things associated with heterosis, we must have to get increase yield. Next one increase reproductive ability. For certain crops if the yield is more, the reproductive ability will be more like, if you consider rice, if more yield is there means, more number of seeds are being produced. So, its reproductive ability will be enhanced in case of maize also.

In case of different crops having a huge number of seeds in them, if the number of fruits are increased then the seed production will be increased also, the reproductive ability will be better also. So, it is also true for most of the crops, most of the food crops as well as some fruit crops, some vegetable crops where, the fruits are produced and within the fruits we can see the seed formation also due to proper reproductive ability, due to increased reproductive ability. Next one, is increase in size and vigor. In certain crops the reproductive ability is not too much changed, but we can see increase in size and vigor.

Let us take an example of spinach. Spinach is a vegetable crop; we eat as a leafy-vegetables. So, there the leaf size could be increased through heterosis. In case of cabbage, the head size could be increased through heterosis. So, their reproductive ability is not being hampered, but the economic part i.e. the leaves, i.e. the head in cabbage those things are being increased through heterosis. And good vigor is also observed so that for the initial stage easily it can achieve the larger head, the larger sized of the leaves are observed easily the increased vigor is observed over there.

Next one is better quality. For certain crops like onion the better quality could be achieved through heterosis also. Normally the keeping quality of onion is not so good, but if we make F_1 it was found that due to heterotic effect the keeping quality of onion is improved. So, well now let us discuss about other implications of heterosis i.e. greater adaptability. Through heterosis we can get greater adaptability how? Suppose, we have a plant having genotype capital A capital A small b small b while, it is being crossed with another parent P_2 i.e. having genotype small a small a capital B capital B. Now, let us assume means two genes are there A gene and B gene.

So, A gene is associated with a particular disease in rice. Suppose it is associated with sheath blight of rice. Ok! While another gene i.e. B gene two different alleles of B gene are associated with rice blast. You know, that gene, for gene hypothesis is there for each and every fungal infection, bacterial infection some genes are available in the plant system also. Ok! Due to the interaction between the effector proteins produced by the fungi or bacteria, and some sort of proteins produced by the plant, this type of interaction occurs then finally, we can see the disease occurrence.

Now, over here suppose for A gene… if small a small a allele is there, then we can see disease susceptibility. Susceptibility to sheath blight of rice while, if capital A allele comes over there either, capital A small a or capital A capital A then, we can see the resistance for sheath blight of rice. Similarly, for B gene if only recessive allele is there, homozygous recessive allele is there, suppose it is showing susceptibility to rice blast, susceptible to rice blast. While, if dominant allele is there, either it is in capital B small b or capital B capital B then it can show the resistance to the rice blast disease. Suppose this is the scenario now let us see how heterosis can improve the adaptability of the F_1 generation plants.

So, over here we have one parent i.e. resistant to sheath blight of rice, because capital A allele is there and it is susceptible to rice blast disease. So, within the field where this genotype is available, some yield loss will be there, due to susceptibility to rice blast while, in another parent if you see here small a small a allele is there. So, due to availability of small a small a allele, those plants are susceptible to sheath blight of rice and it is resistant to rice blast. Now in a field, the occurrence of both the disease may not occur simultaneously, both of the disease may not be prevailed at a time. Now, if we cross these two plants and if we get F_1, what will be the F_1 constitution? It will be capital A small a capital B small b because, from here only one type of gamete will be produced and from here small a capital B type of gamete will be produced upon fusion will be getting capital A small a and capital B small b.

Now over here as the dominant allele of both the genes are there. So, these things will be resistant to sheath blight of rice, as well as it will be resistant to rice blast. So, greater adaptability could be achieved in this way, because in self-pollinated crop, if we think about this scenario that could be pretty easily achieved, because most of the plants remain in homozygous condition, and in F_1 that heterozygosity will be there. In cross-pollinated crops, also in F_1 the heterozygosity condition will be prevailed in most of the cases. So, in this way the greater adaptability could be achieved through heterosis.

Now gradually we will be moving into the inbreeding depression. First of all, what is inbreeding? Inbreeding is mating between individuals which are related by descent or ancestry, mating between individuals which are related by descent or ancestry. So, suppose two plants are being crossed. These two plants have been originated from a particular mother plant earlier. So, somehow these two are related. So, if cross is made between these two, then we can see inbreeding, mating between individuals which are related by descent. The brother-sister mating they can also cause inbreeding, in case of different plants and the highest level of inbreeding could be achieved through selfing. If selfing is done, then the level of inbreeding become maximum. So, it occurs in cross-pollinated species and the species which are reproduced asexually mostly, why? Because in the cross-pollinated species its genotype is highly heterozygous in nature and heterogeneous in nature. So, in our last class we have discussed about the homozygous balance and heterozygous balance.

In the self-pollinated plants they try to maintain the homozygous balance means, if the genotype is homozygous it is maintained through selfing. While in case of cross-pollinated plants, they try to maintain heterozygosity within itself. So, if you think about the cross-pollinated plants or asexually reproduced plants both of them having heterozygous genotype, and within them, within this group of crops a large number of deleterious alleles are available. Suppose, in a plant 5 alleles are there, let us assume A, B, C, D and E five genes are there, for each gene 2 types of alleles could be there. For example, for A, capital A small a, for B, capital B small b, for C, capital C small c, for D, capital D small d, for E, capital E small e different alleles could be there. Now just assume, in case of cross-pollinated species if the genotype is constitution is capital A small a, capital B small b, capital C small c, capital D small d, and capital E small e then, it can sustain, because for, if all of these recessive alleles are deleterious for this plant. ok! Then over here all of them has its dominant counterpart. So, it will mask the effect of the recessive allele, but if due to inbreeding, capital A capital A comes into the population, if small, sorry, small a small a comes into the population or small c small c comes into the population, due to inbreeding then it will be deleterious for the crop. Ok! Inbreeding in cross-pollinated species as they try to maintain the heterozygous balance so, inbreeding depression is also more. So, when subjected to selfing or inbreeding they show severe reduction in vigor and fertility due to its heterozygous balance.