CONVOCATION ADDRESS

By

ARNE MÜNTZING

Director, Institute of Genetics

University of Lund, Sweden

INDIAN STATISTICAL INSTITUTE

11 February 1965

THE IMPORTANCE OF GENETICS FOR THE EVOLUTION AND BREEDING OF CULTIVATED PLANTS

By

ARNE MÜNTZING

Director, Institute of Genetics, University of Lund, Sweden

As is well-known, the development of human culture is very much dependent on the development of agriculture. Without cultivated plants and domestic animals man would have remained at a primitive hunting stage without time and resources for much cultural achievements. However, such a development could be initiated about 10000 years ago when agriculture and animal husbandry had slowly started in the near East. At that time the cultivated fields were small and the yield certainly low, and it was considered to be more important to find good natural pastures for the domestic animals. Thus, it was probably animal husbandry rather than agriculture which was the primary livelihood at that time. Anyhow, the gradual development of domestic animals and cultivated plants facilitated population increase and enabled specialization of the members of human populations into different occupations and trades.

In one way or the other, the domestic animals and cultivated plants must have arisen from wild species, but this has happened at very different points of time. Most cultivated plants are extremely old, other ones are of more recent origin and still others, such as the forest trees, mainly remain at the wild stage. Cases are also known which demonstrate that plants may return from the cultivated stage to the wild. Species that were of importance earlier, for instance certain dye and spice plants, are in our days unessential and have therefore been abandoned and may now have a troublesome existence as weeds. Other cultivated plants are still in culture but are threatened to be superseded by new types.

The way in which our domestic animals and cultivated plants have arisen and the differences between the properties of the wild original material and the domesticated races were first thoroughly discussed by CHARLES DARWIN. Concerning these problems, much can be learnt from his famous book of 1868 *Animals and Plants under Domestication*. Concerning the differences in properties it may just be stated that the cultivated races have more or less abnormal properties which are useful for man but which make them incapable of existing as wild forms.

The domestic animals are almost like living machines with a onesided, almost pathologically high, production. Eggs laid by highbred Leghorn hens must, for instance, be hatched in incubators as the hens have almost completely lost the instinct of sitting on the eggs. But in compensation, such animals produce more than three times as many eggs as their wild relatives. The pathological features of domestic animals are still more marked in such ornamental animals as certain races of pigeons, goldfish and dogs.

The cultivated plants have often larger cells and external dimensions than their wild relatives and they have a good yield that is made possible by a large surface of leaves and an intensive metabolism. They are also able to utilize fully the good and fertilized soil made available to them by suitable agricultural methods. The cultivated plants are further characterized by the loss of various means of seed dispersal, loss of bitter and poisonous substances which at the wild stage protect the seeds from being eaten, loss of mechanical means of protection in the form of spines and thorns, and finally loss of the resting period which is usually met with in wild species before the seeds are capable of germination.

The question may be raised in which way the differences between wild forms and cultivated forms have arisen? Primarily this has occurred through the extremely strong and comprehensive hereditary variation which occurs in all cross-fertilizing organisms. The nature of this variation has been clarified by the science of genetics, and in this year it is precisely 100 years since the founder of genetics, GREGOR MENDEL, published his small but extremely important paper. MENDEL discovered the occurrence of stable units of heredity, later on called genes, which are transmitted from generation to generation. During this process recombination may occur, which means that individuals with new heditary constitutions are formed by regroupings of the genes. MENDEL clearly understood that recombination of a relatively limited number of genes is sufficient to bring about an enormous genetic variation. This is characteristic of all cross-fertilizing organisms, including man. The fact that all of us, who are now assembled here, are different personalities with different physical and mental properties is largely a result of genetic recombination.

Returning to the differences between wild animals and plants and their domesticated and cultivated counterparts, we realize that these differences have arisen as a result of interaction between genetic recombination and selection. If the understanding of recombination is due to GREGOR MENDEL, the principle of selection became thoroughly known to us thanks to the fundamental contributions in this field by CHARLES DARWIN. As pointed out by DARWIN selection may be either natural or human, and in the production of domestic animals and cultivated plants both these factors are often involved. The plant breeder may utilize natural selection in his hybrid material concerning such properties as winter hardiness or adaptation to a certain light quantity per day. If certain recombination products in the breeding material have an insufficient winter hardiness, they will be eliminated in the field automatically, and if they are not adapted to the natural light conditions they will not flower and produce offspring.

Selection in a genetically variable material may often lead surprisingly far. A beautiful example of this is what has been possible to accomplish in the species *kale* (or *cabbage*), *Brassica oleracea*. The oldest cultivated forms existed as early as in the Stone Age, but their appearance is unknown to us. About 2400 years ago the Greeks cultivated two varieties of leaf kale, and the Romans knew a whole series of different kale varieties which however were not so clearly differentiated from each other as the modern varieties, such as cauliflower, white cabbage and curly greens. By genetic investigations it has been possible to analyze the differences between the modern kale and cabbage varieties and to refer these differences to a limited number of genes.

Another beautiful example of what selection may accomplish is represented by the production of the *sugar beet* during the nineteenth century. The sugar beet is originally derived from the wild beet, *Beta maritima*, and from this wild form the first cultivated varieties originated in the Eastern Mediterranean area more than 2000 years ago. The oldest cultivated forms were vegetables of which the leaves were eaten. They were later on followed by white- and red-fleshed salad beets, and during the eighteenth century it had been possible to produce mangels, quite big beets suitable as cattle fodder. In 1747 MARGGRAF discovered that the beet roots contained sucrose, and in the beginning of the 19th century ACHARD succeeded in producing the first real sugar beets after selection in a white-fleshed mangel beet from Silesia. By continuous selection in the range of 100 years the breeders succeeded in raising the sugar contents from originally about 7 per cent to more than 20 per cent, and in this way were able to create a quite new and important species of cultivated plant.

We have now reached the period of real plant breeding, which may be said to imply an evolution which is directed and very much accelerated by man. This field of work got a solid foundation only after the year 1900 by the strong development of basic research in genetics. The constancy of genes, discovered by MENDEL, also explained the uniformity within so-called clones, in which the same individual has been duplicated by some kind of vegetative propagation. Ability for vegetative propagation is a highly valuable property in a cultivated plant and has greatly facilitated the production of improved varieties in such crops as potatoes, sugar canes, bananas, fruit trees, poplars, and many ornamental plants.

On the basis of MENDEL'S discovery it was also easy to understand that in self-fertilizing plants, such as wheat and barley, it is possible to obtain constant, so-called pure lines, just by raising offspring from single mother plants. The constancy in this case is due to the fact that all the sex calls of an individual are quite identical with regard to their genetic constitution. This pure-line method could be successfully utilized in the breeding of self-fertilizing cereals, but later on the breeders found it necessary to supplement this method by intentional and well-planned crosses between parents with various desirable characters. Thanks to the mendelian principle of recombination it is possible in such cases to combine the valuable characters of the parents into one single new variety. This, however, is often rather laborious owing to the fact that the economically important quantitative characters are often conditioned by a cooperation of several or many genes with similar effects.

Work of this kind has been economically highly important and this is also, and perhaps especially, true of the utilization of hybrid vigour. This is a term indicating that certain products of intercrossing are much more vigorous than the parent types. In many species of cultivated plants this hybrid vigour or *heterosis*, has lead to quite remarkable increases in yield. The best example of a successful utilization of hybrid vigour in a cultivated plant is that afforded by the breeding of maize in the United States. The basic research was carried out in the beginning of this century, and through a brilliant cooperation between many workers it has been possible to get a large and valuable collection of inbred lines, which is being continually improved. By different types of intercrossing of these lines and their hybrids high-yielding products are obtained, which have enormously increased the yield of maize. Of the maize material cultivated in 1944 in the corn belt of the United States 83 per cent was hybrid corn, and cultivation of this hybrid material led to an increase in yield of about 600 million bushels.

This enormous development has taken place during the last thirty years. In 1933 very little hybrid corn was cultivated but in the following years the percentage of the total maize area in the U.S., in which such material was used, rapidly increased, and in 1951 it had reached about 80 per cent. At the same time the yield per acre was increased from about 22 to 33 bushels. All this increase, however, is not only caused by the increase in specific production capacity but also by improved agricultural methods. The introduction of such rational methods, regarding, for instance, crop rotation and fertilization, has been stimulated by the use of hybrid maize.

The same process may now be studied in Mexico, where the production of hybrid maize was started in 1943. Excellent results were obtained and the country is now self-supporting as regards maize. This increase in production had induced the hitherto very conservative Mexican farmer to welcome the use of other plant species as well (wheat and *Sorghum*), which in certain regions may be cultivated with greater advantage than maize. Thus, in a few years, a small group of qualified geneticists and plant breeders have succeeded in raising Mexican agriculture to a much higher level than previously. Similar work in other hitherto relatively neglected areas of cultivation may, without doubt, increase to an essential degree the food production of the world. Without the hybrid maize many more human beings would be starving to-day than is actually the case, and the principle of hybrid vigour may also be applied successfully in many other species of cultivated plants.

A typical and very important trend in the development of genetics is the search for the material bodies which represent or carry the units of heredity. It was fairly soon realized that the genes are entirely or predominantly located in the chromosomes, characteristic bodies which are present in the cells of all organisms. For that reason chromosome research is nowadays a necessary feature in the exploration of most fields of genetics. These investigations may deal with the number, shape and structure of the chromosomes, and in all these respects there is a great spontaneous variation which may be increased still more by experimental means.

As to the number of chromosomes, many plant genera comprise species with chromosome numbers forming a multiple series. Such so-called *polyploidy* also occurs in the wheat genus *Triticum*, in which some species have 14, others 28 and still others 42 chromosomes. It has been demonstrated that the species with higher chromosome numbers in this and other cases have been produced by spontaneous hybridi zation between species with lower numbers. As a consequence of such hybridization the chromosome complements of the parents are sometimes added, which leads to the formation of quite new species. To take an example, bread wheat, the most important cultivated plant of the world, has 42 chromosomes, representing three sets of 14 chromosomes. Of these three sets one is derived from a primitive wheat species and two sets from wild species belonging to the neighbouring genus *Aegilops*.

In plant breeding work it has been possible to repeat the synthesis of bread wheat approximately, and in other cases a precise repetition of a process which occurred spontaneously a very long time ago has been obtained. A good example of this kind is the important oil plant *rape, Brassica napus*. This species, which has 38 chromosomes, represents a synthesis of turnip rape (*Brassica campestris*) with 20 chromosomes and kale or cabbage (*Brassica oleracea*) with 18. A re-synthesis of rape has been carried out by several different workers.

The synthetic rape is very promising from an economic point of view, and already now synthetic rape strains have been produced in Sweden which have been found to give about 7 per cent higher oil production per unit of area than the best commercial variety of natural rape. Further, great possibilities are offered by intercrosses between synthetic and natural rape. In part, valuable heterosis effects may be obtained, in part there is the possibility of introducing valuable genes for winter-hardiness, for instance, which are now lacking in natural rape.

Work of this kind has led to economically important products and this is true also of increases in the number of chromosomes within a species, for instance the production of new types of ornamental plants, fruit trees, beets and clover with higher chromosome multiples than in the starting material.

Another highly important field of genetics is devoted to the study of *mutations*, a term indicating the sudden production of new genes from old ones. It is true that the genes are in general constant and highly stable, but in rare cases they may suddently change spontaneously and give rise to new genes. In 1927 it was demonstrated for the first time that such changes may also be experimentally induced by treatment with various types of irradiation or with certain chemicals. Attempts have also been made to produce favourable mutations in cultivated plants. Though this work is far from easy, the great majority of the mutations representing unfavourable changes, it is now quite clear that the induction of mutations represents a new and important plant breeding method. For instance in barley it has been possible in this way to produce some new improved varieties of great economical importance.

Successful results have also been obtained in other crop plants and in microorganisms, including species of fungi, which have been used for the production of antibiotics. It is therefore unquestionable that in future the mutation method will be of great value to agriculture. This is true not only of properties such as yield, earliness and straw-stiffness but also of improved disease resistance, which has been obtained by mutation according to experience from different cereals and from pea nuts.

Research on mutations, especially when carried out in microorganisms, bacteria and viruses, has recently led to wonderful achievements concerning the real nature and mode of action of the genes. It is now clear that the genes have a much more complex structure than was earlier assumed, but at the same time the chemical nature of the genes has been explored. It is now certain that the genes are groups of nucleotide bases, representing parts of long chains of nucleic acid. Moreover, there are only four types of nucleotide bases, called adenine, thymine, cytosine and guanine. It has also become clear that the order of sequence of the four nucleotide bases represents the code system by means of which the genetic constitution determines which enzymes and other proteins are to be formed. In other words, the genetic alphabet, consisting of 4 letters, is able to decide the precise order of sequence of the amino acids in the proteins formed, and it is also known that changes in the genetic alphabet will lead to the production of new kinds of proteins. This, perhaps, represents the beginning of human control of one of the most fundamental features of life.

In the preceding paragraphs I have very briefly indicated some important problems and results in the fields of genetics and plant breeding. As is usual in science these results have been obtained by workers in many countries and thanks to an international cooperation. As you certainly know India has played an important part in this development, and today there is, indeed, quite a large number of qualified geneticists, cytologists and plant breeders not only at various institutes in Calcutta but in many other places in India. All these people are united by the Indian Society of Genetics and Plant Breeding at New Delhi and by the Indian Journal of Genetics and Plant Breeding, of which so far 24 volumes have been published. For all these valuable scientific contributions and for the brilliant ability of many of my Indian colleagues I wish to express my deep respect.

Among the biological subjects, genetics has especially strong contacts with the science of statistics, and for every geneticist basic knowledge concerning elementary statistical methods is necessary. Thanks to these methods it is possible to decide whether, and to what extent an observed difference is significant, and it is possible to analyze the variance by dividing it into various components. Studies of correlation and regression are also indispensable for most geneticists, and for the plant breeder it is necessary to lay out the replications of his field trials according to the best statistical designs available.

Certain fields of genetics are especially dependent on statistical methods. This is primarily true of research on the inheritance of quantitative characters. Related to the statistical methods involved in general resarch on quantitative characters are those methods which are used in animal breeding. The animal breeder often wants to know to what extent a valuable character such as milk production and fat percentage of the milk is inherited to the offspring. Special formulae for heritability meet this demand.

Population genetics is a wide and complicated field including analyses of the important variables mutation pressure, coefficient of selection, and adaptive value of new spontaneous mutations. Other formulae consider the relative viability of heterozygotes and the mode of mating, whether entirely at random or preferential in some way. This, in its turn, leads over to problems of inbreeding and heterosis, which are also highly suitable for statistical treatment.

Last but not least, statistical methods have become more and more important in studies of human genetics. Man has been considered a poor material for genetic studies because no planned breeding work can be carried out, the human geneticist therefore earlier being entirely confined to the study of such human pedigrees as he could get hold of. However, ingenious statistical devices have been worked out which allow important short cuts. Safe genetic conclusions may now sometimes be drawn from direct studies of population individuals, and in general it is now impossible to imagine successful research of human populations without the aid of statistical methods.

I think I have made it clear that statistics is of an enormous importance to genetics, but I am not sure that genetics is of any importance at all to statistics. I gain some confidence, however, in this respect from the existence at this institute of a botanical research unit under the able guidance of my friend Professor Roy. I know that at least some of his problems belong to the field of genetics and that they are successfully treated with a combination of genetical and statistical methods.

During the weeks I have been here, the scope and importance of the Indian Statistical Institute have become more and more clear to me and in proportion to this, my admiration for the Institute has increased. I think it is obvious to all that this great organisation is of fundamental importance to India. It is, indeed, a wonderful achievement that a fine statistical working group and effective organisation provided with all the modern equipments should be built up during a short period of less than 35 years. This, to a very essential degree, is due to the eminent and inspiring leadership of Professor P. C. Mahalanobis who has also been able to surround himself with a large number of competent collaborators.

The Institute functions in many ways. Thanks to the skilful staff available, a wealth of reliable data on the most varied aspects of social and economic life of India are collected and analysed, and this represents the solid material on which the Government may base many of its decisions.

In order to ensure a continuous supply of competent statisticians in sufficient numbers, the Indian Statistical Institute has a second important function, and that is to train and educate students in this field. Though statistics is in the strict sense the central subject, the training programmes comprise studies not only in the related fields of mathematics and economics, but also in various fields of general science. It is obvious that persons with such a comprehensive and thorough training are of eminent value to India, and I realise that the demand for young men and women with such qualifications must be very great.

A third important function of the Indian Statistical Institute is to carry out research. Owing to its international recognition, I knew something in advance of this aspect of the Institute, and during my stay here I have had the opportunity of learning a good deal more about what is going on here by way of applied and fundamental research. Thanks to the Director of the Research and Training School, Dr. C. R. Rao, I have met several staff-members and have acquainted myself with their problems. It is obvious that research in the Indian Statistical Institute has reached a very high level which is equivalent to the standards met with in other important international centres. The reason for this, I think, is not only that it has been possible to gather a highly selected group of qualified Indian scientists but also that, from the beginning, the great importance of international cooperation has been fully understood. International courses in statistics which are carried out each year are an indication of this international spirit, but still more important from the research point of view is perhaps that the Institute has found it possible to invite and to take care of many foreign scientists of whom R. A. Fisher, J. B. S. Haldane, Norbert Wiener and A. N. Kolmogorov will be regarded as the most prominent ones.

When I return to my country, it will be a pleasure for me to inform my colleagues about the outstanding role of the Indian Statistical Institute in its service to India, in its training and research activities, and in its position as an international centre of the greatest importance.

May I take this opportunity to particularly point out to those who are taking degrees today that it has been a great privilege for them to have been associated with this institution and to have profited from the training given here. I am sure that as you go on in life with your professional activities, you will realise more and more the importance of the concept which underlies the structure of this Institute and you will derive great benefit from the many-sided opportunities to which you have had access during your work here.

Finally, I wish to express my deep gratitude for having the honour of speaking to you on this special occasion and for the great privilege of being invited to spend some time at this wonderful Institute.