RECENT WORK IN PLANT BREEDING*

FOR some eight thousand years man has been engaged in the breeding of plants for his own use, and during these long centuries of time there has been a steady improvement of all the plants which provide him with material for food, clothing and ornament. Up to thirty-five years ago this improvement was for the most part haphazard and accidental ; though in fact intelligent selection of the best and most useful varieties was constantly practised, and any new improvements unexpectedly arising were carefully preserved. Actually the progress achieved by these non-scientific but commonsense methods was extraordinarily good, but owing to a lack of knowledge of the laws of heredity it was of necessity extremely slow and often wasteful in effort and outlay.

In 1900 the finding of Mendel's long-lost paper disclosing his discovery of the fundamental laws of heredity caused a complete revolution in breeding. To their credit plant-breeders were quick to grasp the importance of the new facts in helping them to a more speedy and a surer solution of their problems. In all cultivated plants new work was enthusiastically carried through, old varieties were tested and purified and new varieties were raised which contained a preponderance of desirable qualities. The further discovery that all heritable characters, whether structural or functional, were due to the actions and reactions of the minute living molecules known as genes, situated in the chromosome threads of the nucleus of each cell in every plant and animal (including man), was a still greater cause of progress. It was immediately realised that the best results in breeding could only be obtained by an intensive study of the chromosomes and genes of any plant which was being used. This study revealed many startling facts, and provided a complete explanation of some hitherto quite inexplicable difficulties. It is safe to say that the union of the two new sciences of Cytology and Genetics into one was one of the greatest revolutions ever brought about in biological science and is bound to have the greatest possible influence on the future of man.

After thirty years of concentrated experiments by a great number of research workers with millions of plants and animals in the numerous laboratories and research stations which had sprung up all over the world, it was realised that in many cases the limit of improvement had been reached. The existing varieties had been bred to such an extent that their possibilities were more or less exhausted, their desirable genes had all been utilized and all the most desirable combinations had already been attained, though in many cases the ideal had not been fulfilled. Only one thing could give further progress—the introduction of new genes and new methods of combining them with the old genes.

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*By C. C. Hurst, Ph.D., Sc.D., Trinity College, Cambridge, in *The Empire Cotton Growing Review*, Vol. XIII, No. 2, April, 1936.

The discovery that new mutations could be produced by X-raying gave a new stimulus to the work. Unfortunately, as in all natural mutations, the great majority of X-ray mutations are pathological or lethal, so that although their incidence is enormously increased the production of new forms of real value by this means involves considerable labour in testing large progenies. Fortunately a new and extremely profitable method arose in the hybridization of widely distinct species and even genera which, by their combination, brought together entirely new gene-complexes of a highly desirable kind. Hitherto the union of different species had brought about little success owing to the sterility of the hybrids. The discovery that a duplication of the entire chromosome set of the hybrid either in the germ cells or in the body cells (Hurst, 1933, 1935) produced fertile germ cells and progeny and created new species and genera, gave new hope to this branch of breeding which has proved to be amply justified. In this connection the use of X-rays is of great value, for one of the most useful results of this treatment is the duplication of chromosome sets. In an ordinary species this is important, although not of vital importance, since it only increases the size of the individual without producing any other desirable genic changes, but in these specific or generic hybrids it is of the utmost value, for it converts a sterile hybrid into a fertile and pure-breeding new species or genus combining the qualities of the two parent species, and containing a new complex of genes which often in their reactions together give rise to new qualities. Above all the new forms possess greater potentialities for mutation in the greater number of genes, and hence afford more hope for the production of new varieties.

Here we come to the real essence of modern plant-breeding. Once the possibilities of interspecific and intergeneric breeding were realized, the introduction of new genes became an all-absorbing problem. The great work of the modern breeder is the search for new genes, especially those which give resistance to the numerous and devastating diseases which attack crops in every country. Fortunately, it has been discovered that in most genera there are many wild growing species which are immune to the diseases which attack cultivated plants, and by using these species it is hoped to be able to produce disease-resistant plants which will still contain all the desirable points of our best cultivated varieties together with the addition of other good characters which are not yet present.

Under their able leader Dr. N. I. Vavilov, the Russian plant-breeders have been in the forefront of this new phase of breeding. Expeditions have been sent out to every country in the world to collect all the possible species allied to the plants which constitute our present crops, and also to discover new sources of the various commercial commodities, such as fibres, oils, rubber, etc. In addition to the wild growing species there are many ancient species and varieties still in cultivation in remote and outlying districts which contain valuable qualities, especially in their adaptation to peculiar and exacting environments. One of the great problems of modern plant-breeding, besides that of disease resistance, is the production of varieties which will give a full yield under adverse conditions. In a country such as Russia, and within our own Empire (under such diverse conditions as exist in Australia or Canada), there is a great need for new varieties and new types of crops fitted to each particular type of locality. It is useless to expect a high-yielding, disease-resistant plant fitted to normal conditions to function adequately in districts subject to drought or to extreme cold; such districts must have their own varieties specially bred for them. For this purpose the old-type crops of the isolated communities are ideal, for they have, through countless generations of natural selection, become adapted to their environment, which in many cases is of a highly specialized character, since they are usually found in out-of-the-way mountain districts or under steppe or desert conditions. In these districts there is a wealth of new genes to be found in every kind of cultivated plant fitted to all possible conditions.

The experimental stations throughout the world are making exhaustive collections of the likely wild-growing species and of the locally cultivated crops, and from the new gene combinations arising from their hybridization with our existing crops great hopes are entertained.

Cotton.—In cottons work has been proceeding steadily all over the world. In attempts to produce cottons suitable for their diverse environmental conditions the Russians have put in an immense amount of work in studying the genes and chromosomes of varieties and species, and have carried through numbers of hybridizations. At Tashkent, a study was made of ginning percentages by investigating the number and weight of the fibres and weight of seed, and it was found that there was a wide deviation in this respect between different cottons. The number of fibres per seed in seven varieties of American cotton varied from 7·8 to 14·7 thousand, while the weight of a thousand fibres varied from 4·4 mg. to 7·6. mg., and the seed weight from 97·0 to 167·2 mg. In *G. herbaceum* the number of fibres per seed varied from 3·6 to 9·2 thousand, the weight of a thousand fibres from 3·4 mg. to 5·8 mg., and the seed weight from 69·7 to 111·8 mg. Crosses have been made in which it is hoped to combine the higher number of fibres with the heavier weight, and in the second generation of a cross between two lines of *G. herbaceum* some plants arose with the desired combination and showed a ginning percentage of from 7 to 13 per cent. higher than the better parent. In the fourth generation a true breeding line was obtained in which the percentage was 8 per cent. higher than the better parent.

The type of boll in *G. herbaceum* is very variable, but the closed boll proved to be a simple mendelian recessive to the open or semi-open boll, both of which are undesirable in mechanical harvesting. Size of boll was found to be dependent on a number of genes in American cottons, and it was necessary to grow some thousands of F_2 seedlings to obtain the desired types. By crossing with early maturing forms it was also found possible to unite high yield with early maturity. Many other points were studied, and it is pointed out that since a large number of genes are involved in these cottons it is wiser to limit the parental combinations as much as possible in producing new varieties by hybridization, and to grow the largest possible number of progeny. Back-crossing is also useful for reducing the number of segregating types in later generations.

The Transcaucasian Cotton Research Institute have issued a bulletin describing the progress made in the acclimatization of Egyptian Cottons ; descriptions, illustrations and lint qualities of selected new lines are given. The varieties have been divided into six groups based on their maturity periods. Another publication from Moscow gives the spinning qualities of a number of the best improved varieties grown in the U.S.S.R. Varieties of the Pima type of Lower Egyptian Cottons have been grown under varying conditions for comparison. Upper Egyptian types, including Ashmouni and allied varieties, Uplands and strains with medium staple, have also been tested. It has been found that by means of transplantation it is possible to grow high-quality Egyptian varieties in the region of Tashkent, and some selections of Pima can be spun to 120 counts. Longstapled Uplands, however, are superior in yield, and are as good as the Egyptians for spinning 50's and 60's.

The experiments in vernalization of cotton were attended with much success, not only in producing a higher yield under normal conditions, but also in several cases, in increasing in lint length. The seed is moistened and then kept at a temperature of 25° to 30° C. for varying periods. It was found that the best results were obtained after ten to fifteen days' treatment for Navrotskii, fifteen to twenty days for Acala 8517, and fifteen days for the Egyptians ; longer periods caused depression of germination and shorter periods had no effect. The chief effect of optimum treatment seems to be a more rapid completion of the various phases of development rather than any particular acceleration of their inception. All the varieties vernalized germinated from two to three days earlier than the controls, but later stages showed considerable variation. In the American cottons treatment produced a tendency to higher ginning percentage and length of lint, but in the Egyptians the ginning percentage was increased while the lint length was slightly decreased. The flowering period was usually from three to four days earlier, but in Navrotskii it was as much as thirteen days, and in Ashmouni nine. The differences in maturity were often greater, varying from four to fifteen days earlier. In all cases the plants treated in the Russian experiments showed an improvement over the controls and it is probable that this method may be of much value in growing crops in those regions not naturally fitted for them. Certain cases of failure are attributed to imperfection of technique rather than to any deficiency in the treatment, and different varieties gave widely different reactions ; in some cases there were even differences within the varieties themselves. It is pointed out that greater knowledge is needed before the best results can be expected. The effect was that treatment was considerably greater in 1933 (which was a very bad season for cotton-growing in the new regions) than in 1934, when the natural conditions were more favourable to normal growth. Vernalized sowings were made on a large scale on collective farms in 1932, 1933 and 1934, with an increase from 600 ha. to 3,000 ha. under cultivation in the three years. The average yield increase was from 0·3 to 2·5 centner per ha. but on one farm the yield increased in the treated crops was four times that of the untreated.

At Tashkent experiments were also made on the photoperiodism (adaptation to length of light-day) of the cotton plant, subjecting different varieties to daily illumination amounting to 6, 9 and 12 hours against the average of 14 hours of the controls growing under normal conditions. Observations showed that cotton is essentially a short-day plant, which complicates its successful growth in long-day regions, since a reduction of illumination causes early maturity. Different varieties, however, show different heredity reactions corresponding to the position of their original environment with regard to the equator, those from equatorial regions needing the least light and this effect becoming less and less as their place of origin is further removed from the equator. The general effect of the shortened illumination is the production of sympodial branches at a lower level and consequently an earlier production of flowers and bolls. By making the necessary comparative alterations in the daily amount of light it is possible to synchronize the flowering periods of widely divergent varieties and species, and to make crosses hitherto difficult owing to the difference of their flowering seasons in these new regions. Crosses have thus been made between Egyptian cottons with low boll weight and several South American cottons with very large bolls but of short day and perennial habit.

Within our own Empire work on the improvement of cottons is also steadily proceeding, but this is too well known here to need repetition.

Beans.—New varieties of Soya beans have been produced, suitable for conditions on the Ukraine Steppes. Those previously grown proved unsuitable for mechanical harvesting owing to the pods occurring too low down on the plants. Of the new strains produced one is equal in yield to the best imported types and is early maturing, while another provides superior fodder. In Uruguay, where the varieties are successful elsewhere have proved failures, a collection of 233 varieties from widely different sources and conditions has provided ten promising types. Selected lines of these have given very high yields, and others have been bred which are resistant to drought, which normally has a very adverse effect on germinating qualities, both at harvest and sowing. The best of these new lines have a protein content of 34 to 39 per cent. and oil content of 14 to 20·5 per cent. with a yield up to 1,000 kg. per ha.

This wonder plant, the " staff of life " in the Orient, which provides meal, oil, food for cattle and a fertilizer, has also been successfully introduced into England by careful selection of early maturing varieties and their acclimatization for several years by Mr. J. L. North. The remarkable properties of the Soya bean are not yet appreciated by the British farmer, and a book on the subject has recently been written by Miss E. Bowdidge to make its cultivation more popular. It is to be hoped that its value may soon be realized and taken advantage of by its widespread cultivation.

Cereals.—Work steadily proceeds all over the world to produce new improved forms capable of cultivation under diverse conditions, and to provide each district with an ideal variety by hybridizing the highly specialized local cultivated forms and species with the high yielding normal types. The new genera formed by generic crosses between wheat and rye, and wheat and *Aegilops* in Russia and Germany have already been described in this Review (Hurst, 1932), but recently an even more interesting line of investigation has been opened up in the hybridization of wheats with the couch-grass *Agropyrum*. This grass is perennial, and it is hoped thus to produce perennial wheats of extreme hardiness for cultivation under adverse conditions. Three species of *Agropyrum* have been successfully used in crosses at Saratov. The first-generation plants are very luxuriant, forming up to 150 heads on one plant. They show a preponderance of *Agropyrum* characters, which is to be expected since *Agropyrum* is a decaploid with 70 chromosomes (10 sets) while *Triticum vulgare* is a hexaploid with 42 chromosomes (6 sets). The hybrids were all perennial and fully resistant to frost, and the first generation of *T. vulgare* crossed with *A. elongatum* is distinguished by excellent fertility, one plant giving as many as 665 grains. Other crosses showed diminishing fertility according to the parentage. In the second generation wide segregation occurred, but the fertility was higher, the grains being large and vitreous. In the third generation many plants showed quite normal fertility, the grain being mainly of the wheat type. Several of the hybrids showed resistance to rust and smut, and freedom from shattering, with the addition of various other valuable characters, and this new breeding work is obviously of great practical importance. It is evident from the results obtained that certain species of couch-grass have a very close affinity with certain wheat species, their distinction apparently lying only in their two extra chromosome sets. Thus *T. vulgare* may be designated A + B + C and *Agropyrum* A + B + C + X + Y, other species of both having variations. Hence it should not be difficult to fix desirable types in future generations, and it is also probable that some fortunate duplications may occur to hasten the process.

The new genus *Secalotriticum* (Rye × Wheat) (or *Triticale*) is already grown on a large scale. The most notable achievement of the Russian grain-breeders however is probably the distribution of a very large number of improved varieties of the chief grain crops (wheat, barley, oats and rye) especially suited for cultivation in all the main regions of the Soviet Union, including the arid zones. This has been achieved in the north by the production of ultra-early spring wheats and new hardy winter varieties. One of the new early oats is also highly resistant to drought and rust. The hybrid *Avena sativa* × *A. Byzantina* exceed the standard yield by four times, and showed considerable resistance to leaf-rust, and a new rye produced by crossing a local form of Detskoje Selo with Rÿmker also showed a great increase. Further improvements are still required, however, especially in disease resistance. From a close study of the methods used it may be seen that all the desirable new qualities have been introduced by using local varieties in crossing, since they possess the essential genes for resistance which are needed by the existent varieties.

The Russian world collection of wheats shows that there are four groups of early maturing wheats: (1) Arctic, (2) from continental regions of the subtropics, (3) from mountain regions, (4) from countries of periodic rain such as China and Japan. In other respects however, these wheats are very different: those from the north need little warmth but much light, and those from the south are resistant to heat but need little light. By the requisite crossings early maturing forms can be raised with varying reactions according to the latitude for which they are required.

Great improvements have been carried out in India on wheats and barleys so that they can now compete in quality with any in the world. At Pusa, types resistant to all the three rusts prevalent in India have been produced. In Egypt since 1921, work has been carried out with great success in the improvement of cereal crops by hybridizations between the native forms and imported varieties. In Australia, collections of cereals from all parts of Australia and other countries have been made in order to breed types fitted to all the very varied conditions of the continent. Three or four hundred valuable new lines have already been isolated and are undergoing exhaustive trials. All European countries as well as America are working on the same genetical lines, and the work done in cereals throughout the world is one of the greatest tributes to the success of modern genetics.

X-ray experiments with wheats show that each variety has its own particular reaction. The soft spring wheats give a great variety of mutants, while the *durum* varieties give a larger number of mutants but a limited number of types.

In China, work is being done in the hybridization of cultivated rice with the wild forms. A valuable new variety with vigorous growth, resistant to cold and to a high percentage of acidity in the soil, has already been produced. In Japan, experiments with X-rays, ultra-violet rays and temperature changes has induced all the known mutants of rice and other new ones, and in some cases mutants ripened 11 days earlier than the parents.

Lupins.—The Kaiser Wilhelm Institute have put on the market new alkaloid-free lupins which will grow on the most unfavourable light soils and produce extraordinary quantities of green fodder. Crosses between bitter and sweet lupins showed that absence of alkaloid is a simple recessive. The Russians have also done very much in the production of alkaloid-free lupins, having made two and a half million analyses in two years. The great advantage of these new lupins is their high yield and protein content and their capacity for growing on sandy soils where other crops cannot be produced. A common bitter lupin has been discovered with 21 per cent. oil content against the usual 4 to 6 per cent., and it is hoped to combine this new feature with the alkaloid freedom. Disease resistance is also being investigated.

Rubber.—The Russians have made expeditions also to discover new rubber plants suitable for cultivation in their temperate regions. Analyses of 1,048 species of 316 genera belonging to 95 families have been made, and rubber was found in 609 species. The best results were obtained within the *Compositae* family. A plant found in the Caucasus, *Scorzonera tau-saghyz* showed a higher rubber content than any plant known, the rubber being of high quality and easy to extract. Its unusual capacity for regeneration was also a marked peculiarity of this new species.

Tobacco.—In Russia, work is constantly proceeding to combine the hardiness and adaptations of local varieties with the finer flavour of more desirable varieties. Many extremely interesting compound types have been built up containing the chromosome complexes of three species of tobacco. Much segregation occurs, and desirable new types can be fixed in later generations. These synthesized varieties form a valuable reservoir of new and valuable forms, and correspond to the similar experiments in cereals. In America several pure breeding new species and varieties have been built up in this way, by hybridization followed by chromosome duplication or segregation. The use of ultra-violet rays was found to give rise to conditions of greater fertility in the hybrids. Goodspeed and others find that the tobacco plant is a specially good subject for X-ray treatment, and several useful mutants have arisen by this means. In one case fourteen different types were obtained from a single X-rayed sex cell ; seven were pure breeding derivative types, the others are not yet constant.

Much work has also been carried out with such crops as bananas, sugar-beet, cacao, coconuts, coffee, hemp, potatoes and sugar.

In so short a space it is not possible to deal adequately with any one of the many lines of research being pursued, but enough has been mentioned to show how very much alive scientific plant-breeding is all over the world. Just as new genes are being introduced into existent crops, by the utilization of new species and local forms, so other wild species are being tested and tried out to produce new types of crops. Although the Russians have led the world in the exploitation of world resources, yet there are still untapped reservoirs of wild plants in the Soviet Union itself, many of which are promising new sources of rubber, fibres, etc. The great forests of South America are still largely unpenetrated by man, and one may expect vast stores of vegetable wealth to be had there for the seeking. Above all in China there is an unparalleled wealth of species and forms, often extremely localized. The intermingling here of tropical and temperate floras has resulted in the evolution of a vegetation of unequalled richness and variety. Our own plant collectors have shown us to some extent the horticultural treasures which are to be found there, but the great store of economic forms is still scarcely touched. Chinese forms are also generally characterized by a happy immunity from disease, and many cold-resistant forms of fruits, etc., which are at best only half hardy in the case of those now in cultivation, exist in the northern mountains and at higher altitudes in the south. Excessively late or early forms, wide variations of colour, form, size, flavour, yield, etc., promise an almost inexhaustible store of genes for the future. Thus we may look forward to a very considerable improvement in all our economic crops, fruits, vegetables, and flowers within the next few years with special adaptations to all the diverse environments of the various continents. The future of plant breeding is indeed bright, and although much labour will be involved it will be more than worthwhile in the usefulness of the results.