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CONTENTS

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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

HEREDITY AND ENVIRONIC FORCES[1]

THAT the qualities and forms of living things are the final and net result of the action of environic conditions upon ancestral protoplasm is almost universally agreed upon. Unanimous as may be the acceptance of this all-inclusive generalization, yet when the attempt is made to establish the causal connection between organisms and the forces concerned in their development, an accumulation of facts is encountered which lends itself to widely divergent theoretical explanations.

No gain would result from a citation of these countless theories or from a rehearsal of the evidence claimed for the support of each of them. A proper approach to some of the results to be presented, however, makes necessary a preliminary consideration of some of the basal and recognized relations of the cell, or of the organism to the developing complex of external forces. Foremost among the problems that present themselves in such a review is that of the nature of the so-called adaptations. Underlying the practise and extension of botanical science is the untested assumption that, for example, when a mesophyte is grown as a xerophyte, the modifications of structure which ensue are adaptive and fit the organism for dealing with arid conditions. The size and form of leaves de-

[1] Address of the vice-president and chairman of the Section of Botany, American Association for the Advancement of Science, Chicago meeting, 1907–8.

veloped in such cases is determined by the balance of water supply, conducting capacity of the shoot, and the transpiration rate. The combined action of these factors does lead to the formation of organs in many instances that have the aspect of being of increased fitness and efficiency, but results of the opposite character are encountered. Thus, in my own experiments with *Roripa,* the American watercress, it was seen to bear filiform, dissected leaves when submerged, linear dissected leaves when emersed, but when acclimatized at the Desert Laboratory, developed broadly ovate, almost entire, laminæ.

Etiolation resulting from diminished illumination or total deprivation of light has been supposed to induce adaptive elongation of stems and petioles by which the chlorophyll-bearing tissues were carried past obstacles which cut off the light. Long-continued experimental studies have demonstrated that not half of the species tested exhibit such elongation, a greater number showing thickened organs, and other useless alterations.

Illustrations might be multiplied, and a candid estimate of the alterations undergone by the organs of a plant when it is subjected to unusual conditions of temperature, moisture, food-supply and seasonal change usually fails to reveal anything more than a coincidence of direct response and useful purpose, and it is evident that such coincidences must be subjected to the closest scrutiny before being accepted as adjustments conditioned by suitability.

Turning now to structures and functions of a specialized character, normally heritable and characteristic, it is easy to read into them a fitness not actually present, or not possible of causal induction by the factors to which they are supposed to be an adaptation. Thus but recently the investigations of Lloyd complete the proof that the movements of stomata are not adaptive or regulatory with respect to transpiration. Reams have been written as to the automatic and finely balanced valve-like action of these organs with respect to the conservation of water in the plant, yet it is now known that they open, widen and close in response to other stimuli rather than those arising from the turgidity of leaves and the aridity or humidity of the air. The presence of spines and spiculæ on cacti serve to check the depredations of grazing animals, but it would need a devious logic to conjure up a causal relation between the two. These structures are probably due to aridity, but are not in themselves a useful structure in adaptation to this condition: a dozen species of cacti, devoid of spines altogether, are known which live under the most accentuated desert conditions. Morgan also concludes that the capacity of regeneration has been developed without regard to any directly adaptive action, and this exemplification might be extended indefinitely if space permitted. It is not intended to assert the non-existence of direct useful alterations in the organs of plants, and of the functions they serve: Instances of apparent validity are numerous, particularly in rhythmical activities of all kinds, but the entire matter of causal adaptation is in need of a basal reinvestigation from an entirely new view-point.

This leads to a second problem most readily suggested by the time-worn phrase "inheritance of acquired characters," a conception so vague, so widely inclusive and withal so illy consonant in ordinary usage with the facts, that it will soon be quoted only for its historical importance. If by this phrase is meant that an organism makes adaptive response to its environment by adjustments of functions followed by alterations of structure, and that the continuance of the stimulus and of the response results in heritable and irreversible modifications, we have an idea resting upon inference, and based upon suppositions and circumstantial evidence only, since no satisfactory proof has yet been offered to show that a modified soma might impress its divergent characters upon the germ-plasm.

It seems necessary to repeat and emphasize the assertion that no case exists, in which it has been demonstrated, or proved beyond reasonable doubt, that any fully and continuously heritable change has been induced in a plant by the conditions of cultivation, outside of those due to selection, hybridism and mutation. Individuals may be forced to the limit of their variability by culture, and the effect may endure for a few generations when the inciting causes are removed, but it finally disappears. Thus when a species is acclimatized poleward, it shows a seasonal cycle of lessened length, or instead of annual it becomes biennial, this being a fair example of a direct useful and necessary adaptation and one of the clearest that can be found. A return to lower latitudes is followed by a reversion to the original habit, however, a process which may need two or more generations for its completion. The movement of a species toward the equator may result in a perennial habit, likewise of a temporary character.

While satisfactory proof of direct individual adaptation and its heritability is not at hand, and while many of the most highly specialized adaptations are known to have no causal connection with the external agency concerned, yet the possibilities are not to be ignored. The very vagueness of the subject is a challenge, and it is with the view to testing evidence and obtaining new facts, that the Desert Laboratory has established experimental cultures through a range of a vertical mile, from subtropical arid, to alpine humid climates, in which introductions and exchanges already made have been followed by marked somatic alterations. It remains to be seen whether any of these are adaptive, and whether the changes in question are irreversible or not. A decade will be necessary for any intelligent consideration of even the simpler phases of the subject.

It is now pertinent for us to inquire as to the possible stimulative or formative action which external forces may exert on the germ-plasm independently of the somatic or vegetative body, in the production of heritable alterations.

Experimentation upon the subject has, until recently, been carried on with the idea of producing somatic modifications, which might by repetition, or by profundity of alternation, be impressed on the germ-plasm and thus conveyed to successive generations. Recently, however, Tower has carried his work in the induction of new forms of beetles by climatic and other factors, to a point where he is satisfied that the effect of the external agent is directly upon the germ-plasm, with what remarkable results, as set forth in his notable contribution, you are already doubtless familiar.

My own investigations bearing upon this matter were successful in methods in which the action of the experimental agencies upon the germ-plasm was direct and capable of ready demonstration. As announced in 1905 it was found that the injection of various solutions into ovaries of *Raimannia* was followed by the production of seeds bearing qualities not exhibited by the parent, wholly irreversible, and fully transmissible in successive generations.

Encouraged by this success, a number of reagents were used in the following year with *Œnothera biennis,* a plant which had been under observation for some time, and with which I was so familiar as to be able to recognize alternations readily. Of the various tests with this plant, one, which had been treated with a solution of zinc sulphate, gave seeds one of which produced a plant, known to my associates and myself as "F. 206," which differed so markedly from the parental form as to be recognizable by a novice. This form has been tested to the third generation, transmits all of its characteristics fully, and does not readily hybridize with the parent even when grown so closely in contact with it that the branches interlock.

With this additional success, next nine species in the genera *Opuntia, Cereus, Mentzelia, Argemone, Nicotiana, Eschscholtzia* and *Pentstemon,* which were growing naturally in the vicinity of the Desert Laboratory, were operated upon, using various solutions, inclusive of calcium nitrate, potassium iodide, zinc sulphate, and methyl-blue in various proportions from 1 in 250 to 1–50,000 parts of distilled water. Over a hundred thousand seeds were harvested from the treated ovaries and some were sowed in August, 1907. Most of the species in question develop slowly, and the seeds are difficult to germinate under control. I am not prepared, therefore, to make any definite announcement concerning the results, except to say that among the seedlings of *Cereus* are several which seem far from being typical.

The principal contribution to be made at the present time bears rather upon the mechanics of the action involved by this treatment. The original results were discussed with the assumption that the introduction of reagents into the ovary would be followed by action on the egg. In order to test this matter, solutions of methyl-blue were injected in the same manner as the other substances and examinations were made at various times from a few minutes to a day later, for the purpose of gaining some idea of the mechanical behavior of the fluids. The facts obtained from the great tree cactus, *Cereus giganteus,* will best serve as an illustration.

The ovaries of this plant are inferior and one-celled, the cavity having a capacity of about 2 c.c. The inner layer seems to function especially as a conductive tissue, and from it the concrescent funicular stalks arise, bearing the anatropous ovules to the number of several hundred, the whole offering exceptionally favorable conditions for treatment of the reproductive elements.

The large flowers open early in the morning and attract a variety of small bees and gnats, the former probably being instrumental in effecting pollination. If this is accomplished and the temperature rises to 80° F. the flower closes at the end of the day and falls off a day or two later. At lower temperatures, the flowers may reopen on a second or even a third day. The style is 5 or 6 cm. in length and the pollen tubes must traverse its length within twenty-four hours and probably accomplish it in much shorter time. It was, therefore, thought advisable to make injections between 10 A.M. and 4 P.M. of the day the flowers were open, or perhaps on the previous day.

Generally the needle of a charged syringe was thrust diagonally downward until the tip projected into the central cavity, and the reagent forced in by the pressure of the piston, as much as .5 c.c. being introduced in some instances. The use of this maximum amount would cause a visible enlargement of the ovary, but even in such cases the mucilaginous character of the tissues and the high turgidity would quickly close the wound when the needle was withdrawn. With lesser amounts and using the greatest care in manipulation, the operation was followed by the death and casting away of a proportion of the treated ovaries which amounted to as much as 95 per cent. Similar fatalities resulted in other species and in some all methods of treatment were total failures, the ovaries being aborted within a day after being treated. The plants used during the last two years have been growing in a state of nature on the domain of the Desert Laboratory, and the ripening fruits were subject to the ravages of animals, with the result that the packages of seeds harvested represent but a small fraction of the total number of operations. To this destruction was added the inevitable loss of many of the seedlings. It is needless to say that, having used such a large share of effort upon plants, to which not the slightest imputation of "cultivation" could be attached, precautions of the most rigid sort will be used hereafter.

The coloring matter was injected in the several types of ovaries with various results, according to the anatomical features presented. It will be most profitable to continue the discussion by the citation of results with *Cereus*. In this species the coloring fluid, fairly representing one type of action of the several reagents employed, was absorbed almost entirely by the inner lining wall of the loculicidal cavity. The strong transpiration current quickly conveys the reagent upward to where the walls join and coalesce with the tissues at the base of the style. Here a mass of cells a centimeter in thickness was found to be so thoroughly impregnated with the solution as to be distinctly colored.

The funicular stalks had also taken up a large share and this had been conducted out along the concave flanks and through the conductive tissues as far as a mass of thin-walled cells in the outer part of the inner integument, being still separated from the antipodal cells by several protoplasts. The numerous glandular hairs on the funiculi were also deeply stained, probably by contact with the mass of liquid poured into the cavity. The cells surrounding the micropyle had taken up a noticeable amount, probably in the same manner.

Here then is a set of mechanical conditions under which the pollen tube carrying the generative nuclei can not reach an egg without passing through a deeply impregnated tissue at the base of the pistil, coming in contact with scores of charged cells, then after entering the cavity it touches and adheres to many of the impregnated trichomes of the funiculi, and, lastly, in reaching the egg, it must pass the endostomal cells, also heavily laden with the reagent. In the numerous anatomical examinations made, pollen tubes were found which had become stained before reaching the micropyle. In this species, therefore, any alteration in the normal transmission of hereditary characters might very well be ascribed to effects produced in the chromatin or plasma of generative nuclei of the pollen. In other instances the eggs, or rather the embryo-sac might be more easily acted upon by an injected reagent. It is to be said also that the *Cereus* structures might be affected in a different manner by other reagents, but in all cases the pollen tube would necessarily pass through tissues impregnated with the reagent.

The mechanism of the action of the reagents employed is not capable of ready analysis. It may be readily appreciated, however, that any withdrawal of water, or introduction of substance, would be followed by a disturbance of the balance existing among the various ions in the chromatin and plasma. The slightest disturbance of a protein, or even a modification of the relative rate at which various processes might be proceeding, would account for the profoundest changes in qualities borne by mature plants produced. The modifications, of whatever character they may be, are probably beyond observation by cytological methods.

In addition to these direct effects it is within the range of possibility that the application of the reagents might set in motion the processes resulting in polyembryony, or parthenogenesis: it is to be noted, however, that the facts at hand do not suggest such a happening in the forms already obtained, but in the extension of these experiments to various types of reproduction these things must be taken into account.

While the method described is of interest as having possibilities for our intervention in the evolution of organisms, it becomes much more so if similar results may be expected in a state of nature.

Such a parallelism is to be found in the unusual intensities of the environic factors of light, temperature, moisture, etc., which have been used by Tower in the modifications of *Leptinotarsæ* which he has secured. Here, of course, the entire soma as well as the germ-plasm is subjected to the action of the inciting agent. The various distributional agencies by which seeds are constantly being carried far beyond the limits of the customary range of their various environmental conditions must result in the exposure of developing individuals and mature germ-plasm to unusual intensities which might well be responsible for such results. Thus, a stream takes its rise near the alpine plantation of the Desert Laboratory, and flows out on the desert a few miles away, and a mile lower down. Doubtless hundreds of thousands of seeds are carried to the lowlands each year. Some of these develop into individuals which carry out reproduction. This is usually done in the native habitat, at actual temperatures of the tissues not above 60° or 70° F. Down below, spore formation, reduction divisions and fertilization may ensue in temperatures 40° to 50° higher, a difference capable of being endured by the shoots of some plants, now being tested, and which might well cause irreversible developmental changes. Other factors of the environment may operate in a similar manner. Again, it is to be recalled that the actual formation, or intrusion of active substances in the ovarial tissues, may result from the stings of insects, the mycelia of parasitic fungi, the penetration by foreign pollen, or the egg or pollen may become subject to radium emanations or to X-rays or other forms of radiant energy. Still another possible action is to be accounted for: in hybridization the foreign pollen tubes, carrying the generative nuclei of the pollen parent, may encounter substances in the invaded pistil to which they are not usually subject, with the result that their capacity for transmission of parental characters may be altered, and qualities may thus appear in the progeny which are not active in either parent.

A hypothetical consideration of the known facts as presented by the many species in which mutation has been seen to occur seems to lead to the conclusion that the changes upon which discontinuity of inheritance rests, ensue previous to the reduction divisions in plants. The alterations which take place in my experiments however, follow disturbances not brought to bear upon the germ-plasm until after the second or third division following the reducing divisions and are perhaps separated from this act by a considerable period of time. It will be necessary, therefore, to alter our present conception of mutation, or to conclude that another form of alteration in heredity has been discovered. The former alternative seems possible and preferable. The forms induced may indeed have a cytological basis similar to that which occurs in bud-sports or vegetative mutations, about which but little is known.

The opportunity does not permit an extended and thorough comparison between the results obtained by Tower with beetles and those by myself with plants, but the following points may be noted: The experimentally produced derivatives of beetles diverged from the parental type principally by one main character, with correlated variability in others. The induced forms in plants show many new qualities of fairly equal importance, so far as such things may be estimated, and these might be quite independent of each other. The new forms of beetles crossed readily and were readily swamped by the parental or other types. The new plants do not hybridize freely, if at all, even when grown with branches interlocking with the parental type. The few tests with the derivatives of *Raimannia* in New York and at the Desert Laboratory show it to be less capable of endurance to these climates, both of which are foreign to the parental type, than the parent. The derivatives of *Œnothera biennis* show equal endurance with the parent in the native habitat, and at the Desert Laboratory (2,700 ft.), but exceed it at the montane station (8,000 ft.). The changes produced in beetles are supposed to be a purely stimulative effect in the growth or maturation period of the egg, while those of plants may be due to similar action, or to the direct chemical disturbances produced by the reagents, during the period following the reducing division.

A restatement of the principal protheses of the work in hand upon the relation between environic and other factors and heredity will be profitable in closing. These may be briefly given as follows:

The forms and qualities exhibited by organisms represent the total effect of environment, but it can not be shown that this has been brought about by direct adaptation; many of the most highly specialized and useful structures bear only an indirect relation to the factors to which they bear a useful relation. Neither has it been demonstrated that an individual adjustment made by the soma is impressed upon the germ-plasm, and transmitted unchanged, although the inference is strong that this may be involved in rhythmical functions and perhaps in range of variability.

Various agencies experimentally applied in such manner as to affect the germ-plasm only have caused the origin of forms bearing fully transmissible qualities not presented by the parental type. The new characters have been found to be fully heritable, and the induced forms do not always hybridize with the older types.

The induction of such new forms in plants may be accomplished by reagents applied to the generative nuclei carried by the pollen-tube, and probably by action on the embryo-sac, in the period following reduction division. Mutations have been taken, on hypothetical grounds, to be based on changes occurring previous to these divisions.

The various agencies used in inducing new forms in this manner may have a stimulating effect, or may cause direct disturbances in the chemical balance of the substances in the chromatin and plasma. Similar action may result from unusual intensities of various environmental conditions, or to accidental intrusions on germplasm of many kinds. The alterations in question may well be beyond detection by cytological, or by any direct method of examination.

When the nature of the induced changes is once ascertained, the inductive agents might be applied in such manner as to guide the course of development and thus actually control the evolution of organisms. In so doing, man, the conscious organism, would assume a dominating rôle in the world of organisms and create relations among living things not now existent.

D. T. MacDougal

TENDENCIES IN PATHOLOGY[1]

During the first half of the nineteenth century the science of pathological anatomy was created. Its rise was part of the development in the natural sciences which marked the beginnings of the intellectual expansion of the century, and its growth has continued unbroken up to the present day. Out of the science of anatomical pathology, which stands as the foundation subject of those disturbances in structure and function that constitute disease, there arose other sciences the pursuit of which has served to increase our understanding of the nature of disease. Chief among these are the sciences of general pathology, erected on the foundation laid by the discoveries in physiology, of pathological chemistry, which has grown out of the study by physiologists of the chemical changes connected with the different organic functions, and of the discovery by organic chemists of the nature and constitution of the compounds composing the organic skeleton and produced in the course of organic metabolism, and of bacteriology, that quickening subject, emerging Minerva-like out of the epochal investigations of spontaneous generation and the biology of microscopic plants and animals, which gave to medicine in a few pregnant years an era of discovery in the domain of the causation and the specific treatment of disease unparalleled in all medical history. The resultant of the discoveries in the newer fields of pathological knowledge constitutes the period of etiological pathology which, dating its beginnings from the middle of the last century, is to-day the dominant influence affecting medical thought. It is my wish to present to you briefly, as can only be done in the limits of a short address, certain of the tendencies in the study of pathology to be discovered at the present time.

To compass this broad field superficially even would demand more of your time than would be permissible on this occasion, so great are the activities to-day with which the subjects of general pathology, biological chemistry and bacteriology are being pursued. I have, therefore, adopted a very arbitrary course in the choice of subject-matter to bring before your attention and I have chosen to allude briefly to certain fields of inquiry in general pathology and to deal somewhat more fully with certain newer problems in bacteriology which are commanding at the moment the attention of the best laboratories, and I have left the fascinating field of biological chemistry to be dealt with by a far abler hand than mine.

The causation of disease is manifold, the reaction to abnormal influences is varied. The forces which divert the normal functions and bring disease into being are only in part external, at the time of their operation, to the body. All parasitic plants and animals, which disturb function or alter structure and produce disease, are essentially extrinsic agents of injury and have been introduced from without either during intrauterine life, of which there now exists objective proofs, or later in the period of post-fetal existence. The many causes of occupation diseases, so-called, in which we recognize the introduction into the body chiefly with the inspired air, but also by way of the digestive tract and possibly by way of other mucous surfaces and the skin, of injurious foreign particles, are at present only slightly understood and act not wholly,

[1] Address of the vice-president and chairman of Section K, Physiology and Experimental Medicine, American Association for the Advancement of Science, Chicago meeting, 1907.