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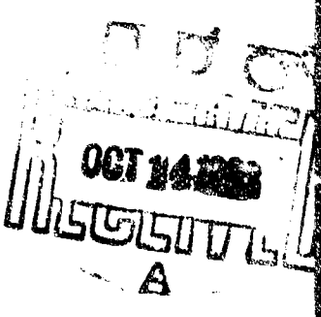

DEPARTMENT OF THE ARMY
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HOST-PARASITE RELATIONS

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The interest in the physiology of diseased plants evoked by comparative pathological observation during the past century in spite of insufficient knowledge of the causes of infection was set back several decades as a result of the study of the increasing number of pathogenic agents discovered and described and the efforts made to suppress them or to obtain resistant strains through breeding. The attempts made to explain such resistance or to open up the way to indirect determination of such resistance resulted in conclusions that varied from one time to another almost like the winds of fashion with emphasis being placed on different parameters at one time or another (osmotic pressure, pH, etc.) while hardly leading to any deeper understanding. It was not until the increasing difficulties met with in breeding to increase plant resistance to disease became apparent coupled with the better opportunities offered by the advantages of working systematically with the further development of plant protective agents that, in view also of the deeper insight also gained into the physiology of plants, "there was a new revival of congenital pathology and the study of predisposition to disease" (Braun, 1965) bringing to the forefront the physiological aspects in the "science of plant pathology" (Horsfall-Dimond, 1962); the pathological analyses of the etiological factors giving rise to infection were undertaken along with other analyses, too, basing on the new advances made in the theory and methodology of general plant physiology. The "problem of resistance" was characterized by investigations of the causes of inherited resistance and the possibilities of induced resistance in terms of specific formulations of questions and far-reaching interpretations. One is allowed

perhaps to ask the question whether such an approach is a good one, particularly since almost exclusive interest is shown one specific feature of "resistance", namely, hypersensitivity, because it is the factor that most evidently counteracts or neutralizes the damage caused by parasites and this generally appears to occur in a highly specific manner. Such a narrowing of the goal that has been set, often occurring in a not fully conscious manner or inadvertently readily leads to an insufficient appreciation or to neglect of other types of alternatives or possibilities which could also have far-reaching effects in limiting such developments and can also lead to inadmissible generalization of the knowledge gained about a definable phenomenon, thereby exaggerating its importance. We should not make excessive claims on behalf of the specific concept of resistance that is still only comparative in terms of description (Fuchs 1948) when considering theoretical matters. One can hardly conclude that a specific form of resistance is the rule in nature on the basis of the fact that an exceptionally small number of infectious diseases appears percentage-wise compared with the total number of imaginable host-parasite relations between higher and lower plants (Kuč, 1963). Let us put aside the problem of the host's environment and consider the relationship between specific parasites and the varieties of hosts suited to their peculiarities; then the laborious work of breeding for resistance will show that high resistance and freedom from attack are a really rare phenomenon with average susceptibility to attack from a parasite occurring in general much more frequently than extreme "susceptibility" to a parasite.

One could object against this that one could encounter a wide variety of strains and stresses that the organism would be subjected to, even by way of cells attacked at first only indirectly by an infestation or infection and where they would not have been destroyed, where stimuli would occur that would take effect through "vegetative regulation of the cell environment." Apart from the fact that such a reaction is based on other mechanisms than the so-called "resistance" phenomenon being given such special emphasis, the very raising of such an assumption as to the existence of such a mechanism automatically brings up the question of how at all any parasitic symbiosis is possible.

First of all we must limit the scope of our subject. In a straightforward, literal sense parasites are organisms who live at the expense of their host, regardless of whether they are pathogenic or not (Horsfall, Dimond 1962). The

host-parasite relationship has different meanings, though, depending on whether we consider the relationship between the parasite and the host individual or whether we consider the relationship between the parasite and the cells or groups of cells that are directly attacked, forming the basis of the parasite's attack on the host. From the first standpoint organism that destroy a part of the host plant and nothing more could even be looked on as parasites. From the second standpoint, more in keeping with a physiological point of view, parasites are only those organisms which develop over a longer or shorter period of time in the still active, living host cell, even if the latter is killed by them after some period of time. Our treatment of the subject concentrates on this line of argument. In so doing we wish to exclude in so far as possible all those cases wherein the cells are destroyed upon penetration by the parasites while on the other hand we wish to rule out all those effects which during the subsequent course of the disease spread through the organism (as in diseases accompanied by withering) or which are differentiated from the attacked or destroyed areas as demarcation reactions.

We are therefore going to concentrate on pronouncedly biotropic parasites. Such parasites have predominantly a narrow range of hosts. They can only "attack" specific species or families of species that enable them to complete their development true to type. Apart from the fact that the parasite must be able to tolerate the environment on the surface of the host tissue (such as caused by secretions or excretion), it must be able to penetrate into the intact host cell.

Observations of movements aimed at seeking out the host by motile zoospores in a watery environment have in all cases clearly shown that directional stimuli are given off by the host, setting in motion the process of infection; diffusion fields of attracting and also repelling and perhaps also "exciting" materials whose nature is inadequately known at present. Isolated observations, the most recent being those on Polymyxa betae by Keskin (1964) describe the trial contact of the zoospores with the host root and suggest that contact stimuli also prepare the way for the invasion. Motion pictures show that a number of temporally definable individual stages of development precede the penetration process (Keskin-Fuchs unpublished). Observations by Flentjes (1959) on Pellicularia filamentosa tend to substantiate the significance of various

stimulus patterns during the infection process while S. Dickinsons' investigations on rust (1949) point to the importance of the condition of the surfaces.

It will be necessary to wait for further analysis of such stimulus patterns. Secretions of the host could play a decisive role in such patterns with the formation of such patterns being induced by the excretions of approaching potential parasites for which convincing evidence is given by Gäumann's group for the orchid combination of mycelium and suckers. Here, too, one should also mention the "phytoalexines."

A stimulus pattern also regulates the formation of appressoria or similar organs; the cell wall is then penetrated; the actual forces involved will not be dealt with in any greater detail at this point. It is surprising, though, to see the extraordinary speed at which Polymyxa betae is able to penetrate into a root-hair cell within a fraction of a minute (Keskin-Fuchs, unpublished). In the end this penetration brings on within the cell an increased streaming of protoplasm, a thickening of the protoplasm, an enlargement and traumatropic displacement of the nucleus, a reaction picture that has already been observed in carefully scratched or injured cells (Küster, 1927). Unfortunately still hardly anything at all is known about the alterations in protoplasm fine structure; it seems, though, that the endoplasmatic reticulum in the vicinity of the would thickens and that there is a clustering or accumulation of mitochondria and ribosomes; the pores in the envelope of the enlarging nucleus also appear to grow larger (Mollenhauer et al. 1960), rounding out the picture of stimulus-conditioned activation. The picture could be further rounded out by additional investigations into the changes in ultrastructure during penetration and after damage or injury occurs.

The similarities between traumatic and infectious alterations in the cell which in both cases can also be radiated in some degree to neighboring cells raises the question of the differences in the subsequent results of the reaction induced; after mechanical injury the wound is sealed by secretion of "wound substance," a process that occurs in many infections in the form of encapsulation. After the penetration of biotropic parasites this reaction is suppressed or limited (Berlin and Bowen, 1964) and the demarcation reaction in surrounding tissues is also striking. No general defense reaction sets in. This exclusion of the natural reaction result appears to

me to be the most important indication of susceptibility to biotropic parasites, whether or not the partner is tolerated during the further course of the symbiosis with symbiosis here being taken as having De Bary's meaning as a superior concept.

Does the stimulus evoking the response occur upon penetration of the cell wall that today is no longer looked upon as being dead, or does it occur later upon touching the protoplasm boundary layer by destroying the microstructures or charge patterns? This too has yet to be explained as does the question about the primary local energy sources and about the ATP [adenosine triphosphate] that is used up by intensive metabolic processes and its replenishment; such an activation is indicated, too, by increased gaseous metabolism a few hours after the infectious process has begun in potato epidermal cells after infection with Phytophthora infestans (Tomiyama, 1963).

The first consequences of injury and of penetration by parasites are similar. This suggests that the stimulus generated by the parasites may be subdivided into a traumatic and a parasite-generated component. The traumatic stimulus would be non-specific but could create an activated physiological condition in the vicinity of the penetrating hypha. Would this be the prerequisite to the growth and flourishing of obligate biotropic parasites, setting up the environment that hitherto could not be provided outside of the host plant? The parasite-generating stimulus components would go into operation within this environment, neutralizing the normal course of restitution or replenishment and making possible the subsequent arrangement. The purely traumatogenic stimulus which constitutes an injury occurring only once as a single event should be differentiated from the long-term, continuing injury that occurs with the growth and heightened attack by the parasites.

Before we go on to further follow up this arrangement we should ask the question as to whether the multiplicity of biotropic parasites should be all looked upon in the same way such as we have more or less done in summarizing our presentation. Basically the results obtained with a single specific model should be generalized and applied to other cases with increasing cautiousness as finer distinctions are noted among more distinctly differentiated materials. It also appears to be advisable to differentiate among different types of biotropic parasitical symbioses. The simplest case of all and one that has hardly been studied at all from the physiological

standpoint is offered us by the lower Phycomycetes that live within the host cell and destroy it practically without producing any symptoms; no attempt will be made at this point to mention other differentiations.

The much-studied case offered by Phytophthora infestans (Tomiyama, 1963) gives us an example of a period of time during which in cases of tolerated host-parasite combinations the partners continue to live together for some time before the host cell begins to show the typical pathological symptoms of deterioration; the less the tolerance between host and parasite the sooner they die off.

In tolerated combinations of Peronospora, Uredinea and also Erysipelothrix there is a long-lasting stage free of symptoms or characterized only by disturbed cohabitation. It appears that the final death of the host cells is due more to starvation than to any actual conflict; many of the representatives of both of the first two families mentioned are able to live on for a long time with the host in a harmonious pathological condition for the most part accompanied by hyperplasia of the host tissue but there is neither time nor space to go into any further details at this point.

We will limit ourselves to the question of whether the differences mentioned in the course of cohabitation between Phytophthora infestans and, for example, Puccinia graminis, and corresponding cells of their host are to be attributed to basic differences in metabolic relations (the problem of different reaction standards in leaves and stems that also applies to Phytophthora [Fuchs, 1961] is not considered at this point). This is further pointed to by the observation that in the first case differences in the toleration shown by different combinations of species and varieties can be readily explained on the basis of different rates of speed of similar processes (Müller, 1958; Tomiyama 1956) and in the second place by the fact that it is hard to raise any objection to it, which we cannot go into at this point.

Are the differences to be found only in the apparently still specific demands made by the various rusts which are still looked upon today as being obligate biotropic parasites (as well as other physiologically comparable types)? Or should we be allowed to conclude in favor of basic differences in the powers of attack? It remains an open question whether the newly discovered capability of Phytophthora infestans to break down nucleotides (Page, 1964) could directly substantiate such a difference as

long as no study has as yet been made of nucleotide metabolism in diseased tissue and as long as we remain unsure whether similar capability is to be found or not in the rusts, for example.

If we resort to physiological-biochemical investigations of host-parasite combinations without following up and going through all of the blind alleys in the maze of possibilities involved in metabolic processes then we will still even today run into what are still almost insuperable difficulties.

The alterations that occur in a short time after penetration of a parasite can hardly be identified or recorded because the portion of the disturbed tissue affected is too small a part of the total mass of the leaf. The differences between diseased and healthy tissue noted during later stages of their shared existence can hardly be attributed in any clear-cut manner to either one or the other of the partners and we must delve much deeper into this question. Even the early consequences of "eusymbiotic" (about one to three days after infection) and "dyssymbiotic" stages of development of their commonly shared life brought about in rusts, for example, due to differences in susceptibility (Roemer, Fuchs and Isenbeck, 1938) and due to displacement of metabolism (Sempio, 1938) cause a basic shift to occur in the relationship to the uninfected subject of comparison.

Most investigations are carried out for obvious reasons with somewhat concentrated inoculations. Even observation with the naked eye shows that individually isolated rust pimples develop more strongly than densely packed together rust pimples that compete with one another in the focus of infection. The alterations that have yet to be described are almost unquestionably also conditioned by the density of the infection (Heitefuss and Fuchs, 1962) (Lunderstädt, 1964). No further explanation is needed for the fact that the metabolism of the host will be differently affected depending on whether the infection is widely scattered or densely concentrated. A greater distinction should therefore be made in the future as to whether the change in metabolism is really due to a genuinely parasitogenic alteration of metabolism or whether the change is due to the total load on leaf metabolism caused by the density of infection, leading to an earlier or more rapid alteration and the resulting consequences.

Failing to take into account the difficulties mentioned above one finds general agreement on the whole

among many different investigations (Shaw, 1963) with respect to the following alterations arising due to infection while maintaining in so far as possible the same environmental conditions:

1. The increase in respiration that occurs.

2. The increase in the share of direct oxidation compared with the HMP (hexosemonophosphate) route in the increased conversion of sugar coupled with a simultaneous increase in the pyridine nucleotide level and, above all, of the NADPH [abbreviation not explained in text] level, too (Rohringer, 1964) and a redox potential that is shifted towards the reductive end (Kaul and Shaw, 1960).

3. A shift among some of the acids in the tricarboxylic acid cycle (Siebert, 1961; Rudolph, 1963; Von Sydow, 1964).

4. The increased synthesis of protein and aromatic compounds which mostly discussed straightforwardly as such and only questionably as "phenol bodies."

These alterations have an inner correlation. They make it possible to determine the existence of infection on the second or third day but they do not reach their maximums until towards the end of the dyssymbiotic stage at the time of spore eruption excepting protein synthesis which subsides earlier.

This standard reaction "resembles essentially the features of traumatogenic modifications" (Fuchs, 1961) as has recently been demonstrated for the first enzymatic steps along the HMMP [abbreviation not explained in text] path (Farkas et al., 1964). This shows on one hand that the plants react along the lines of a somewhat coordinated program even under a wide range of different stresses, the different ramifications taken by such reactions being attributable to different hereditary constitutions while on the other hand raising the question of whether and how a parasite can intervene quantitatively and qualitatively to produce a regulating or controlling effect within this framework. Perhaps in case of infection, too, the basic modifying effect should be subordinated to a traumatic stimulus component. It appears to us today, though, that one cannot admissibly "equate the reaction to infection completely with traumatogenic alterations" (Fuchs, 1961).

The increased respiration is not the outcome of any decoupling of oxidational phosphorylation (Shaw, 1963) as had long been incorrectly assumed. The discovery that

it was actually during the period of greatest respiration that one noted the existence not only of an increased nucleotide level but also of a higher ATP/ADP ratio (adenosine triphosphate/adenosine diphosphate) (Heitefuss and Fuchs, 1961) is being confirmed over and over again.

The increased specific activity, particularly of ATP (Heitefuss, 1964 and unpublished) tends to substantiate the existence of a rapid conversion of energy-rich phosphate which also occurs in the unbroken incorporation of phosphate in other metabolites which cannot be dealt with in detail at this point (Heitefuss and Fuchs, 1961; Heitefuss, 1964; Quick, according to Shaw, 1963). There still remains open the possibility of a space-occupying intensification of the endoxidation associated with the tricarboxylic acid cycle in spite of the increasing proportion of the HMP-route. One cannot rule out participation by photosynthesis in ATP-formation in the area around the field of infection (Thrower, 1964). In any case this would provide the necessary energy requirements for further syntheses.

The increased direct oxidation (HMP) may provide the necessary nutrients and this may obtain additional support from the increased activity of the enzymes mediating the first steps (Lunderstädt et al, 1962; Kiraly and Farkas, 1962). The quick rise in hexokinase activity (Lunderstädt et al. 1962, Lunderstadt, 1964) that has been confirmed (Lunderstädt, in press 1965) could act as a starter.

A transitory preliminary rise in glucose-6-phosphate dehydrogenase activity could be associated with the increased ascorbic acid level, the significance of which we cannot deal with here any more than with the possible relationships with indolyl acetic acid metabolism (Shaw, 1963).

The unusual later increase in the activity of the HMP-path enzymes corresponds to the enrichment of these enzymes in the rust rather than to any metabolic exchange or interrelationship between the partners (host and parasite).

The new synthesis of enzymes corresponds throughout to the increased protein content of infected tissues (Shaw and Colotelo, 1961) as does the appearance of new iso-enzymes (malic dehydrogenase!) (Staples and Stahmann, 1964) and one can be sure that similar findings can be expected in connection with other enzymes. It should be emphasized that this kind of synthesizing activity is directly attributable to an increase in the RNA (ribonucleic acid) content

(Rohringer and Heitefuss, 1[illegible] and specific activity (Heitefuss, 1961) in the nuclei. (Whitney et al., 1962). Quantitative differences in the ribonucleic acids are suggested (Wolf, unpublished).

The increased formation of "phenol bodies" and the accumulation of their oxidation products has already long been held to be a valid indication of hypersensitive intolerability (Farkas and Kiraly, 1962). It should be looked upon, though, as a somewhat unspecific symptom or accompanying phenomenon associated with necrobiosis after various heavy stresses (Roemer, Fuchs, Isenbeck, 1938). It also appears in non-necrobiotic tissue after injury as well as prematurely in compatible infection, for example, as the synthesis of aromatic amino acids (Rudolph, 1963; Von Sydow, 1964, etc.), as aromatic acids, coumarin, etc. It is inadmissible, though, to use the overall designation, "phenol bodies" on the basis of group reactions (Sondheimer, 1963), a habit that is all too easily acquired; the physiological significance of very closely related compounds can undergo fundamental changes (Sondheimer, 1963) even though having the same basic structures because the kind and distribution of the various substituents can also vary over a wide range and the given proportions of such compounds existing at any one time can also bring about a decisive shift in the effects on enzymes, for example. Considering the multiplicity of the possibilities for intervention possessed by these materials and their preliminary stages as metabolites and anti-metabolites in various types of enzyme systems occupying key positions in metabolism and the fact that clusters of similarly constructed but physiologically different substances come into being in pathological reactions, some reservations and restraint would appear to be in order in the discussion in spite of the large amount of data that has been accumulated and the many attempts to explain its significance; this is all the more true since the question of the syntheis routes in higher plants has not yet been completely cleared up. Both the traumatic and the strictly parasitic components of the infectogenic stimulus give rise to a multiplicity of syntheses and allow apparently dormant paths to be traveled. This is also brought out by a clear example that generally has nothing to do with so-called "phenol bodies;" one of the keto-acids found in the Brassicacea that were investigated for the first time only after they had been infected by certain biotropic parasites giving rise to hyperplasia (Nielsen, 1960) was also to be found in demonstrable quantities in healthy Brassica kaber (Nielsen, 1963).

We also look upon the formation of phytoalexine (Cruickshank, 1963) as another expression of such activation of dormant potential for synthesis; its formation is actuated not only by various attacking organisms but also as a result of modified traumatic attacks and is not directly tied in with necrobiotic processes it would seem. Its basic structure seems to be characteristic for specific families or species; it should therefore be taken into account within the framework of chemotaxonomic considerations. It is clearly significant in the determination of the range of hosts, judging by the low sensitivity of pea parasites to pisatin, of bean parasites to phaseolin, etc. (Cruickshank, 1963). It would appear to us questionable whether they have a decisive effect in determining finer differences in tolerability.

Breaking off at this point in our fragmentary sketch of certain physiological relationships, the question of tolerability should be briefly mentioned, hypersensitivity, the specificity of which with respect to various species is regulated through mutual adaptation of host and parasite (theory of the corresponding gene, gen-for-gen hypothesis; Flor, 1959; Rohringer et al., 1962). In the sense of an all-or-nothing decision the question comes up as to why the metabolic processes are finally guided into various channels only after some considerable time has elapsed since the onset of infection which in one case may permit a tolerated development of the parasite while in another case it may lead to degeneration of the affected cells whereupon the parasite ceases its growth and dies. A number of investigations agrees on the fact that temperature changes can determine the subsequent course of the reaction during the first three days or so (Radulescu, 1933); this indicates that the first physiological arrangements to take place immediately after the onset of infection are unstable and readily influenced. Later on the normal course of the reaction has already been predetermined and in case of intolerability it proceeds in a similar way or in the same way regardless of whether the final result has been determined by specific combinations of species or varieties or by temperature effects (Heitefuss, 1964). Neither does the nature of the infection play hardly any part in the outcome. The reaction is determined by a still unexplained first or primary process; most of the reversal processes hitherto described fail to show such an outcome. As a precaution the question should be left open as to the extent to which the "phenol bodies" that have accumulated to a certain degree should be identified with the

beginnings of a tolerated course of infection; characteristic of these bodies is their subsequent oxidation and condensation accompanied by increased "phenoloxidase" activity, a special problem (Farkas-Kiraly, 1962, etc.) that we must also pass over at this point like also the question of the biochemical changes that take place during the final stage of association between host and parasite; in our opinion they contribute very little to any understanding of the primary and hence the decisive reciprocal action. They are exclusively associated with the meeting of two genotypes each of which is capable of forming tolerable combinations with other genotypes.

Differences in the content of materials on hand before infection or produced subsequent to infection in the host and parasite offer no basis for explanation of such differences; here, then, we would have for the most part only slightly plausible working hypotheses that only have the effect of pushing the true problem into the background. This also applies to attempts to find an interpretation on the basis of increased enzyme proteins or phytoalexines, even though the accumulation of such products locally (for enzymes generally in sweet potatoes, Stahmann and Weber, 1964; for phytoalexines, Cruickshank, 1963) can give rise to broadly effective protective barriers against secondary infections.

In closing, three questions remain to be discussed:

1. Interpretation of the changes that have been described to occur in the parasite and the host and in their tissues.

2. The question of the meaning of a receptive condition.

3. The question of the information triggering the different reaction paths.

Both the host and the parasite participate in the transformations mentioned. It is not easy to estimate the extent to which each participates; one can be sure that during the course of their association there is a shift to the benefit of the parasite which during a later stage accumulates a large part of the photosynthetically assimilated C^{14} as shown by automatic microradiography tests (Von Sydow, 1964) as well as other activities requiring nourishment (Shaw, 1965, etc.). The difference between the tissues in the infected area and intermediate uninfected tissues did not turn out to be as great in the automatic radiographs as previous investigations would

have led one to believe, perhaps due to the relatively time at which the readings were taken. One notes around the points of infection and less clearly around injured areas that a change takes place in the tissues which stands out particularly clearly as "green islands" upon yellowing of the leaf; it then gives the impression that they draw their sustenance from the surrounding cells (Roemer, Fuchs and Isenbeck quoted by other sources). In these apparently altered areas free of fungus hypha the photosynthesis activity persists longer and starch (Wang, 1961) and ATP (Thrower, 1964) accumulate in specific zoning areas; the shift in the ATP/ADP ratio may perhaps be correlated with this fact. Thymidine (Staples and Ledbetter, 1960) and cytidine (Nielsen and Rohringer, 1963) are favored or predominate in the host cells or their nuclei in these areas; there is an increase in the RNA level (De la Isla, unpublished). Ever since the first proofs were given of the accumulation of P^{32} at points of infection (Gottlieb and Garner, 1946) numerous investigations of the most various kinds have shown these areas to be a "dominance field" (Shaw and Hawkins, 1958) acting as a point of attraction for the saccharose in assimilable form in the leaves (Von Sydow, 1964) as well as a great variety of other materials from other parts of the plant (Shaw, 1963). There is a reversal of the flow of materials in competition with the vegetation cone and meristems (Daly, 1963, etc.), a drain that is brought about by the activity of nearby organs and the uptake and intra-plant distribution of P^{32} and other materials, too (Shaw, 1963). The parallel with kinetin-induced centers of attraction is frequently mentioned. This analogy does not however seem to us to fully explain the green-island-phenomenon.

The discovery that kinetin and benzimidazole (Samborski et al., 1958, etc.) are able to re-establish the capacity for synthesis in the aging leaf in intolerable host-parasite combinations that retain the reaction norm (or re-establish it when broken by various effects) is important substantiation of the concept of the physiological similarity of infected and aging tissue (Shaw, 1963; Farkas et al, 1964); certain similarities in the course of earlier discussed metabolic processes also tend to substantiate this idea. We take an opposite position with respect to this idea for the present with some reservations. Most of the ideas developed about the physiology of aging in connection with the study of ripening fruit should not be carried over and applied unquestionably to other organs. Important processes of synthesis go on within the favored

[illegible] depleting that part of the leaf tissue not affected and causing it to age faster in spite of the usually heavy inoculation. This prevents one from considering as superfluous the question of whether this rapid aging may not be more a consequence of the intensity of infection than of any conflict between host and parasite. Furthermore infected leaves can be distinguished from naturally aging ones also by the fact that when in competition with actively growing tissue it draws materials to itself instead of giving them up; analogies drawn to the findings that have been made and which could easily lead one astray should first be made the subject of differentiated formulations of the question concerned for further analysis.

The problem of the host's sphere that still requires much more analysis of the specific form of expression occurring on invasion by obligate biotropic parasites such as rusts will not be taken up in any greater detail here; we assume that the penetration of the parasites into the host cell (under some conditions also brought about by a chemical stimulus emanating from the host cell) creates a trauma that activates the host and makes it receptive to a pathogenic stimulus that disturbs the normal course of healing of the wound; it enables the host to convert a specific information received from the parasite into a specific command controlling metabolism; receptiveness to such a stimulus would be the first requirement for further common association between host and parasite. Specific influences that bring about successful infection and favor a tolerated association between host and parasite (in a similar way to the influences that irritate injuries such as precisely applied, non-damaging temperature treatments, etc.) could give added weight to the importance of a non-specific activation as a prerequisite to cooperation or interaction between host and parasite. The recently determined breaking down of host specificity gives rise to further thoughts in this direction. Careful injury, previous infection with Uromyces (see also other older observations on the encouragement given to yellow rust when Tilletia attack is going on (Dillon-Western, 1927) and brief warming of a leaf enabled Phaseolus to become infected by the untypical Erysiphe mildew (Yarwood, 1963). An otherwise impossible infection of wheat by barley mildew is said to have occurred together with wheat mildew in a mixture (Mosemann and Grely, 1964). A material that is formed after heat treatment is said to be able to transfer untypical receptivity to other plants (Jarvis, 1964). Even with all the reservations that could be brought up against

this confirmation of similar attempts by Salmon (1906) which had hitherto failed to appear during all these years, the question still seems to be oper. It is conceivable that for still unknown reasons it may be possible to bring about a condition in the host through previous infection or other conditioning by a congenial parasite whereby an uncongenial parasite could take hold, perhaps in keeping with the hypothesis developed by Rubin and Oserezkovskaya (1959) to the effect that tolerated growth requires that the host should be able to adapt its metabolic condition, making it similar to that of the parasite. Even a non-specific stimulus in the direction of synthesis activity could contribute towards such an end.

It is still not possible today to give any conclusive demonstration by way of experimentation that such a hypothesis is true but it may, perhaps, be demonstrated in the near future. According to first investigations of the ultrastructure around the edges of rust haustoria (Ehrlich and Ehrlich, 1962) the latest pictures of Albugo candida (Berlin and Bowen, 1964) not only show gland-like structures forming a "secretory system" in parasites but also abundant tubular and vesicular structures in the cytoplasm of the host in the vicinity of the haustoria ends together with an enrichment of ribosomes characteristically associated with metabolic activity; this suggests to the author the idea that the possibility of life for biotropic parasites "depends on the secretory mechanism of the host which is specifically triggered by the parasites"; being picked up by those cells that are excited by the traumatic stimulus components such an induction could perhaps be passed on to the neighboring tissue in the green-island-area in a form modified by the metabolic situation, triggering the chain reactions described; just as a second infection of potato storage tissues gives rise to non-specific defense by synthesis of enzymes (Stahmann and Weber; Stahmann, 1964) or the formation of phytoalexines (Cruickshank, 1963), which, though non-proteins, should be looked upon as interferon (Atanasoff, 1964). It would be worthwhile to investigate whether any such protein may play a significant part in the hitherto but little investigated cases of "recovery" or latency of fungus infection, also perhaps in cases of gall formation induced by fungus. The assumption of induced enzyme formation appears to us to be more appropriate for plant subjects than the idea of antibody formation in the sense of immunity reactions of sera (Stahmann, 1964).

Lastly we come up with the question of the decisive, controlling information; this should be seen from two different standpoints, namely, on one hand as a controlling influence that enables the infection to take hold and on the other hand as a complementary instruction bringing about tolerability or harmony between host and parasite. Both of them require that the host cell should be susceptible to the information; if this is not the case then the general defense mechanism remains intact as the sole response to the attack, whatever form that mechanism may be thought to take. Specific syntheses are triggered in the receptive, activated cell. If one admits that it is possible for the system of regulation to be effective along the lines presented by Jacob and Monod even in the interrelationships between the cells of host and parasite in close contact with each other (Flangas and Dickson, 1961) then one could develop hypotheses that present a plausible picture of the cohabitation of host and parasite and of the differences in tolerability (Heitefuss, 1964). The ultrastructures admit of the formulation or conception of such regulatory units even if it appears perhaps premature, identifying "regulator genes" with resistance genes (Laubscher, 1963).

One can do nothing more than philosophize about the basis of the exchange of information. If it is possible that an exchange of primary information carriers takes place then is the information transmitted by RNA messengers from cell to cell, are there, then, only specifically acting reaction products which intervene efficiently in the metabolic interactions between host and parasite or do lesser changes take place in reaction rates or in the gradient of material to bring about a decisive reversal or transformation of metabolism? The specificity of the receptivity and tolerability relations suggests the idea that the primary decision as to the course of the reaction in the partnership of host and parasite does not require any long, round about path. The undeniable similarity of the changes in metabolism that have been described to date under the widest variety of stress conditions all points in the same direction.

The many and various complications involved in metabolism depending on both heredity and environment, the qualitative and quantitative possibilities of variation of which cannot but be vaguely imagined considering the necessarily largely isolated individual investigations of a subtle nature offer a broad field for research together with the central information problem. Successful treatment of these problems often requires even deeper

knowledge of the physiological interchanges that go on within healthy plants than we possess today in spite of all the progress that has been made in understanding the basic modes of reaction. We would point out with some measure of melancholy hindsight the earlier, simpler attempts at finding suitable interpretations; now the problem has been pushed back into the molecular area; plant physiologists and pathologists hope that further research will do more than provide a deeper understanding of pathological processes; perhaps it will also point the way to better treatment, a problem that we have made no attempt to discuss in this paper.

Bibliography

Atanasoff, D., 1964; "University of Interferon Information," Phytopath. Z. (Journal of Plant Pathology), 50, 326-358.

Berlin, J.D. and Bowen, C.C., 1964; "Host-Parasite Interference of Albugo Candida on Raphanus Sativus," Am. J. Bot., 51, 445-452.

Braun, H., 1965; Geschichte der Phytomedizin (The History of Plant Medicine), Parey, Berlin.

Cruickshank, I.A.M., 1963; "Phytoalexins," Ann. Rev. Phytopath. 1, 351-375.

Daly I.M. and Krupka L.R., 1962; "Effect of Puccinia graminis tritici on Organic Acid Content of Wheat Leaves," Plant Physiology, 37, 277-282.

Dillon-Weston, W.A.R., 1927; "The Incidence and Intensity of Puccinia glumarum Eriks. on Wheat Infected and Non-infected with Tilletcia tritici," Ann. Appl. Biol., 14, 105-112.

Dickinson, 1949; "Studies in the Physiology of Obligate Parasitism," Ann. Bot. (London) N.S., 13, 89-104; 219-236; 345-353.

Ehrlich H.G. and Ehrlich M.A., 1963; "Electron Microscopy of the Host-Parasite Relationship in Stem Rust of Wheat," Am. J. Bot. 50, 123-130.

Farkas G.L., Deszi L., Horvath M., Kisbin K., Udvardy I., 1964; "Common Pattern of Enzymatic Changes in Detached Leaves and Tissues Attacked by Parasites," Phytopath. Z., 49, 343-354.

Farkas G.L. and Kiraly Z., 1962; "Role of Phenolic Compounds in the Physiology of Plant Disease and Disease Resistance," Phytopath. Z., 44, 105-150.

Flaspas A.L. [illegible] Watson I.G., 1961; "Compensatory Genetic Control of Differential Compatibility of Rusts," Qua. Rev. Biol., 36, 254-272.

Flentje N.T., 1959; "The Physiology of Penetration and Infection" in Plant Pathology, Problems and Progress 1908-1958, Madison, 1959.

Flor H.H., 1959; "Genetic Control in Host-Parasite Interactions in Rust Diseases," Plant Pathology Problems and Progress 1908-1958, Madison 1959.

Fuchs W.H., 1948; "On Some of the Basic Concepts of Plant Pathology," Z. Pflanzenkrankheiten (Journal of Plant Diseases), 55, 65-69.

Fuchs W.H., 1961; "Considerations on the Problem of Resistance," Ber. Dtsch. Bot. Ges. (Proceedings of the German Botanical Society), 74, 343-359.

Gottlieb D. and Gasner J.M., 1946; "Rust and Phosphorus Distribution in Wheat Leaves," Phytopathology, 36, 343-359.

Heitefuss R. and Fuchs W.H., 1961; "Investigations of Phosphate Metabolism in Wheat Plants After Infection with Puccina graminis tritici," Naturwissenschaften (Natural Science), 48, 505-506.

Heitefuss R. and Fuchs W.H., 1963; "Phosphate Metabolism and Oxygen Uptake in Wheat Plants after Infection with Puccinia graminis tritici," Phytopath. Z., 46, 174-198.

Heitefuss R., 1964; "Changes in the RNA Content of Wheat Plants having Differentiated and Temperature-Controlled Resistence to Puccinia graminis tritici," Z. Pflanzenkrankh. 71, 154-158.

Heitefuss R., 1964; "Investigations of the Physiology of Temperature-Controlled Degrees of Resistance of Wheat and Puccinia graminis tritici," Thesis, Göttingen, Phytopath. Z. (in press).

Heitefuss R., 1964; "Oxygen uptake, Phosphate and Nucleic Acid Metabolism of Wheat Plants in Relation to Environmentally Controlled Resistance to Puccinia graminis tritici," Symposium Biochem. Probleme der Kranken Pflanzen (Symposium on the Biochemical Problems of Diseased Plants), Aschersleben.

Horsfall J.G. and Dimond A.E., 1962; Plant Pathology, 3 volumes, Academic Press, New York.

Jarvis W.R., 1964; "Thermed and Translated Induction of Endophytic Mycelium in two Powdery Mildews," Nature 203, 899.

Kaul R. and Shaw M., 1960, "The Physiology of Host-Parasite Relations," VI., Can. J. Bot., 38, 395-407.

Keskin B., 1964; "Polymyca betae n. sp., a Parasite in the Roots of Beta vulgaris, Particularly during the Early Development of Sugar Beets," Arch. Mikrobiologie, 49 348-374.

Kuč, J., 1963; "The Role of Phenolic Compounds in Disease Resistance," Connecticut Agr. Exp. Sta. Bull., 663, 20-25.

Küster E., 1929, Pathologie der Pflanzenzelle (The Pathology of Plant Cells), Berlin.

Laubscher F.X., 1963, "Genetic Basis of Stem Rust Resistance," Nature, 199, 719-720.

Lunderstädt J., 1964; "The Activity of Some Enzymes in Carbohydrate Metabolism of Wheat Plants after Infection with Puccinia graminis tritici," Phytopath. Z., 50, 197-220.

Lunderstädt J., Heitefuss R. and Fuchs W.H., 1962; "The Activity of Some Enzymes in Carbohydrate Metabolism of Wheat Plants after Infection with Puccinia graminis tritici," Naturwissenschaften 17, 403.

Mollenhauer H.H., Whaley W.G. and Leech J.H., 1962; "Cell Ultrastructure Responses to Mechanical Injury," J. Ultrastructure Rev. 4, 472-481.

Mosemann J.G. and Greely L.W., 1964; "Predisposition of Wheat by Erysiphe graminis f. sp. tritici to Infections with E. gram. f. sp. nordei," Phytopathology 54, 618.

Müller K.O., Meyer G. and Klinkowski M., 1939; "Physiological-Genetic Investigations of the Resistance of Potatoes to Phytophthora infestans," Naturwiss. 27, 756-758.

Mukherjee K.L. and Shaw M., 1962; "The Physiology of Host-Parasite Relations," XI. Can. J. Bot. 40, 975-985.

Nielsen J., 1960; "Further Investigations of the Pathological Physiology of Pernospora parasitica on Brassica oleracea," Phytopath. Z., 40, 117-142.

Nielsen L., 1963; "Parasitically Induced Changes in Ketoacids of Brassica spp.," Can. J. Bot. 41, 314-316.

Nielsen J. and Rohringer R., 1963; "Incorporation of Cytidine H3 into the Primary Leaf of Wheat Following Infection with Puccinia recondita Rob. ex. Desm.," Can. J. Bot. 41, 1501-1508.

Page O.T. 1965; "Degradation of RNA by Phytophthora infestans," Phytopathology 55, 259-261.

Person C., Samborski D.J. and Rohringer R., 1962; "The Gen for Gen Concept," Nature, 194, 561-562.

Radulescu E., 1933; "Contributions to Knowledge of the Field Resistance of Wheat to Puccinia glumarum tritici," Planta (Berlin) 20, 244-286.

Roemer Th., Fuchs W.H., Isenbeck K., 1938; Die Züchtung Resistenter Rassen der Kulturpflanzen (Breeding Resistant Crop Varieties), P. Parey, Berlin.

Rohringer R., 1964; "Drifts in Pyridin Nucleotide Leds during Germination of Rust Spores and in Wheat Leaves after Inoculation with Leaf Rust," Z. Pflanzenkrankh. 71, 160-170.

Rohringer R. and Heitefuss R., 1961; "Incorporation of P32 into the RNA of Rusted Wheat Leaves," Can. J. Bot. 59, 263-267.

Rohringer R., Samborski D.J. and Person C.O., 1961; "Ribonuclease Activity in Rusted Wheat Leaves," Can. J. Bot. 39, 77-81.

Rubin B.A. and Oserezkorskaja O.L., 1959; "The Hexose Monophosphate Respiration Pathway in Potato Tubers," Acad. Sci. USSR Biol. Ser., No. 2, 257-264.

Rudolph K., 1965; "Further Biochemical Investigations of the Host-Parasite Relationship using Puccinia graminis tritici as an Example," Phytopath. Z., 46, 276-290.

Salmon E.S., 1906; "On Specialization of Parasitism in the Erysiphaceae," Ann. Mycl. 5, 172-184.

Samborski D.J., Forsyth R.F. and Person C., 1958; "Metabolic Changes Detached Wheat Leaves Flouted on Benzimidazol and the Effect of these Changes on Rust Reaction," Can. J. Bot., 36, 591-601.

Sempio C., 1950; "Metabolic Resistance to Plant Diseases," Phytopathology 40, 799-819.

Shaw M., 1963; "Host-Parasite Relations of Rusts," Ann. Rev. Plant Pathol. 1, 259-294.

Shaw M., Ocloteio N., 1961; "The Physiology of Host-Parasite Rebot," Can. J. Bot.

Shaw R., Hawkins A.d., 1958; "The Physiology of Host-Parasite Relations," V., Can. J. Bot. 36, 1-16.

Siebert R., 1961; "Biochemical Investigations of Host-Parasite Relations as Exemplified by Puccinia graminis tritici," Phytopathol. Z., 40, 221-244.

Sondheimer E., 1963; "Discussion Commenting on Kuc, 1963," Connecticut Agr. Exp. Sts. Bull. 663, 25-30.

Stahmann M.A., 1964; "The Biochemistry of the Host and Parasite in Some Plant Diseases," Symposium Biochem. Probleme der Kranken Pflanzen (Symposium on the Biochemical Problems of Diseased Plants), Aschersleben.

Staples R.C. and Ledbetter M.C., 1960; "Incorporation of Tritium-labelled Thymidine into Nuclei of Rusted Bean Leaves," Contr. Boyex Thompson Inst. 20, 349-351.

Thrower L.B., 1964; "Photophosphorylations and Starch Metabolism in Association with Infections by Obligate Parasites," Phytopathol. Z. 51, 425-436.

Tomiyama K. 1963; "Physiology and Biochemistry of Disease Resistance of Plants," Ann. Rev. Phytopathol. 1, 295-324.

Von Sydow B., 1964; "On the Uptake of $C^{14}O_2$ by Wheat Leaves after Infection by Puccinia graminis tritici," Göttingen thesis; Phytopath. Z. (in press).

Von Sydow B., and Durbin A.D., 1962; "Distribution of C^{14} Containing Metabolites in Wheat Leaves Infected with Stem Rust," Phytopathology 52, 169-170.

Wang D., 1961, "The Nature of Starch Accumulation at the Rust Infection Sites in Leaves of Pinto Bean Plants," Can. J. Bot. 39, 1595-1604.

Whitney H.S., Shaw M. and Naylor J.M. 1962; "The Physiology of Host-Parasite Relations," XII, Can. J. Bot. 40, 1533-1544.

Yarwood C.E., 1963; "Predisposition to Powdery Mildew," Phytopathology, 53, 1144.