Some Biochemical Factors of Disease Resistance in Plants.

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THE ability of plants to withstand the effects of extremes of climate or the invasion of parasites is a highly variable quality. Thus, it is common to find a few plants which are able to resist these extraneous influences for considerable lengths of time while others succumb readily. The occurrence of such resistant types has been made use of by botanists, physiologists and plant breeders for diverse purposes. The factors that contribute towards this capacity are of much practical importance and may be classified under the two main heads:—(*a*) morphological or structural, and (*b*) physiological or biochemical.

Our knowledge of disease resistance is derived mainly from animal pathology, in which rapid advances have resulted in the development of immuno-therapy, leading to the protection of individuals from infection. The applications of serum-therapy, chemo-therapy and vaccines are the outcome of researches in the above field. Unfortunately, these procedures do not lend themselves to such fine manipulation with plants as in the case of animals. The reason for this lies in the essential difference between the two groups indicated by Quanjer,[1] Blackman[2] and considered in detail below. In the first place, the nature of immunity itself varies in both the cases. Thus, while acquired immunity plays a large part in protecting animals including human beings from external infection, natural immunity is the most important factor in vegetable life. Secondly, the existence of a circulatory system in animals makes possible the movement of blood to the distant organs, in consequence of which an infection is followed by a general bodily reaction. In plants the lack of such a system is perhaps mainly responsible for the localisation of disease for considerable lengths of time. Again, the existence of this circulatory system in animals has rendered possible the utilisation of serum-therapy technique, whereby immunity acquired at one point is rapidly translocated to different points in the body to control infection. On the other hand, new organs are developing very rapidly in plants and immunity induced artificially at one point cannot be easily transferred to other parts. Even if such a process is conceived of, it is very much inferior to that of animals, and the anti-bodies formed in the older tissues are transmitted only with greatest difficulty to the constantly forming organs. It is obvious, therefore, that serum-therapy cannot be successfully applied to plants. Although this is true to a large extent, more recent investigations by Carbone and Arnaudi,[3] Nobécourt[4] and Chester have made[5] possible the application of vaccination technique in plant protection. In animals, moreover, general bodily reaction is so effective that acquired immunity lasts for considerable length of time, whereas in plants such immunity is not long-standing, and is subject to highly fluctuating external factors such as soil, climate and nutrient supply. Furthermore, while recovery from a disease protects normally an animal from subsequent attacks of the same malady, such recovery in plants does not necessarily immunise them from later invasions of the parasite. Lastly, instances of artificial immunisation of a susceptible plant with a weak or attenuated strain of a known virulent parasite are still rare—a phenomenon which is so successfully applied in the control of animal disease. The recent work of Kunkel[6] indicates the possibility of protecting plants from virus infection such as that of mosaic in tobacco and aucuba by inoculating them with attenuated strains of the infective principle. The effect of these is, however, visible on the plant, such as mottling, etc. Further work is necessary, therefore, to define the conditions of this process.

Nature of disease resistant factors.—The factors that control or modify infection by parasites (including viruses) are mainly two-fold:—(*a*) structural, and (*b*) biochemical. It is futile to separate the two, since the distinction between them is not well defined. It is important, however, to recognise that mechanical or anatomical features play a large part in preventing the parasite from gaining access into the plant tissue, while the physiological condition of the plant determines the establishment of nutritive relations between the host and the parasite. Thus, the plant juice exerts a direct biochemical influence on account of its immediate nutritive value in the early stages of infection. It is possible, therefore, that in some cases, the sap may not be quite suitable for the proper development of a parasite, while in others, the juice may constitute an ideal medium for the vigorous growth and rapid multiplication of the invader. It is sufficient to refer to the work of Zimmermann[7] in this connection. In the process of resisting their entry, plants may exude, by exosmsis, materials which may either hinder or help the regeneration of the disease producing agent. The application of poisonous chemicals externally through dusting and spray treatments is based on the above principle, whereby the poison is made readily available to the organism in the process of feeding on such plants.

Isolation of inhibitory substances.—In Cabbage rot Mallmann and Hemstreet[8] observed a liquefaction and subsequent dissolution of the entire tissue. The extract containing the dissolved material was highly active, even when considerably

[1] Quanjer, H. M., *Rev. Pathol. Vegetal. de Entom. Agric.*, 1923, **10**, 22.
[2] Blackman, *Brit. Assoc. Rept. Presid. Address to Section K.*, 1924.
[3] Carbone, D., and Arnaudi, C., *L'Immunita Nelle Piante*, Milano, 1930.
[4] Nobécourt, P., *Contribution a' l'etude de l'immunité chez les vegetaux* (Bailliere, Tunis), 1928.
[5] Chester, K. S., *Quart. Rev. Biol.*, 1933, **8**, Nos. 2 and 3.
[6] Kunkel, L. O., *Phytopath.*, 1934, **24**, 437.
[7] Zimmermann, A., *Centl. Bakt. Abt. II.*, 1925, **65**, 311.
[8] Mallmann, W. L., and Hemstreet, C., *J. Agr. Res.*, 1924, **28**, 599.

diluted, in inhibiting the action of the organism producing soft rot. The lytic principle of the extract resembles bacteriophage in this respect that its potency is not diminished by repeated transference of cultures. It will add greatly to our knowledge if further examination of the same is made. A similar principle was isolated by Wagner from plants infected with pathogenic bacteria.[9] Although this was precipitated by protein precipitants, like ammonium sulphate, its exact nature is still obscure.

Individual chemical compounds in relation to disease resistance.—Cook and Taubenhaus observed early that organic acids and tannins inhibited growth of organisms chiefly fungi (?). In their study on the toxicity of tannins, they showed that the capacity of the host plant to resist the entry of parasites was traceable to the presence of certain chemical substances rather than to structural differences. They assumed that tannins were responsible for this, but discovered that the fungi experimented with did not behave uniformly with tannins : some were more susceptible than others. Furthermore, sodium tannate was found to be less potent than tannin itself. It was therefore suggested that although tannins by themselves may not be chemotactic, their reaction would vary in association with and in presence of other substances occurring in plant cells, a view for which no adequate evidence is yet forthcoming. Subsequently, Cook and Wilson[10] confirmed the above observation in their investigation of the chestnut bark blight disease. Cook and Taubenhaus studied also the toxicity of vegetable acids and oxidising enzymes, in relation to fungi,[11] and showed that the development of root rots is traceable to an oxidase which acts on gallic acid in presence of oxygen to produce a tannin-like substance. This capacity diminishes on ripening, thus rendering the mature fruit more susceptible than the tender one.

Walker and his co-workers were the first to correlate resistance to disease with the occurrence of definite chemical entities. According to them, white variety of onions is highly susceptible to *Colletotrichum circinans* (Bark) which causes onion smudge, while yellow and red varieties are quite resistant.[12] In their subsequent studies since they have noticed a definite correlation between the quantity of acid detected and the degree of pigmentation, *viz.*, the deeper the colour, the greater the amount of protocatechuic acid present, the above findings are of considerable significance. It may be remarked here that this substance is generally found to occur combined in catechol tannins, resins, gums and anthocyan pigments which are normally present in plants. Therefore it will be of great interest to know whether tannins play a part in disease resistance. In virus diseases of plants, including spike of sandal, no such correlation has so far been established. It is, however, of importance to observe that with the onset of spike, diseased leaves are found to contain more tannins,[14] among which the pyrogallol type is more predominant, while in the healthy or unaffected ones the catechol group of tannins is largely present. In a similar way, the colour of the bark shows distinct change to an intense brown colour as the result of spike infection.[15] To what extent, these factors aggravate or modify the insect attack or the visitations of the carrier of infection, is a problem of fundamental importance in the control of this disease.

Reaction of tissue fluid.—Comes first pointed out that the invasion of plants by fungi and other parasites was dependent on the sugar content and controlled by the acidity of the medium,[16] a greater sugar value and a low acidity of the juice being conducive to the rapid multiplication of the organism. He further observed that to this end, sugar and acids occurred in inverse proportions. Thus, low sugar content was correlated with high acidity and *vice versa*. This provides additional evidence to the observations of Cook[17] that the acidity is a natural defence against parasites. Unfortunately, however, the findings of Comes regarding the relation between sugar content and acidity could not subsequently be substantiated by either Mumford in his studies on curly top of beets[18] or, by the author from his investigations on the spike-disease of sandal.[19, 20] It is pertinent here to remark that increased acidity is a favourable condition for the formation of reducing sugars from disaccharides. Comes' observation of in-noticed a similar condition.[22] On the other hand, Hurd[23] could not correlate acidity in wheat, with resistance to disease. In sandal spike, the author (*loc. cit.*) observed that with the onset of disease, the reaction of leaf tissue fluid turns slightly more alkaline than that of the corresponding healthy ones but became more acidic with the advance of the disease. No apparent relation could be traced between sandal plants growing with different hosts. It may be concluded that acidity is not an important factor in the resistance of sandal to spike. Mumford examined beets which were susceptible or resistant to curly top. He could not detect any difference in the initial reaction of the juices of the two varieties.[24] Moreover, he found a greater concentration of

tracing disease-resisting factors to initial acidity or to buffer values of the juice is due to the fact that these studies have been made on the expressed sap which may not represent the fluid actually present within the cells. Though spike disease induces abnormal changes in the buffering processes of sandal, Srinivasan and Sreenivasaya were unable to trace any striking difference in the buffers of sandal, grown in pots in association with different host plants.[31] It is difficult to reconcile this with Sreenivasa Rau's observation that the host plant associated with sandal determines the composition of the parasite.[32] Obviously factors like age, environmental factors play considerable part in the metabolic activities of sandal.

Enzymes in relation to disease resistance chemical factors which determine susceptibility to disease in plants.

Subsequently Lees showed that water content

decrease with the onset of disease. Preliminary study on the rôle of lime on the apparent ease with which infection can be artificially transmitted