forth, under controlled environmental conditions, will be published elsewhere in medical literature.

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STUDIES IN CERTAIN FACTORS AFFECTING THE RESISTANCE OF PLANTS TO INSECT PESTS

As far as the writer is aware, only two scientific papers have been written on the general subject of resistance of plants to insect pests. The first of these was published by McColloch[1] in Kansas in 1924, and the second by Lees[2] in England in November, 1926. An interesting but popular account of the problem was given by Treherne in 1917.[3] It has also been ably discussed in Wardle and Buckle's "Principles of Insect Control"[4] and in certain other text-books. Lists of references to observations on the resistance of plants to insect pests[5] are to be found in the published work of Mumford, Wardle and Buckle, McColloch, and Lees.

Resistance to insect pests may be due either (1) to some external protective agency, such as thickened epidermis or cuticle, the development of hairs, etc.; (2) to some condition of the cell-sap which repels the insects, such as the presence of certain oils, alkalis, organic acids, etc., or (3) though not actually unattractive or repellent, the sap may be unsuited to the insects' food requirements. The word "resistance" is also used in another sense—to denote the plant's ability to survive or "pull through" severe insect attack. In this case, though the insects still attack the plant, the damage is not apparent. Vigorous, healthy plants are said to "outgrow" the checking influence of attacks more readily than weaker, ill-nourished plants.

The problem of resistance is so complicated that the use of a special nomenclature seems advisable. The writer has proposed[6] the term *epiphylaxis* for external protective agencies, and *endophylaxis* for the internal protection afforded by biochemical qualities that render the plant unattractive or repellent or unsuited to the food requirements of insects. The importance of the water-balance as a factor in the resistance of plants to insect pests has recently been discussed by Mumford and Hey (1930).[7]

Examples of epiphylaxis.—An example of epiphylaxis is to be found in the protection afforded by the thick skin in certain varieties of *Citrus*. In Florida, it is the thin-skinned varieties of *Citrus* that suffer most from the attacks of such plant-bugs as *Nezara viridula* Linn. The thin-skinned tangerines, *Citrus nobilis* var. *deliciosa* and Satsumas, *C. nobilis* var. *unshiu* are the first choice of these bugs; oranges, *C. sinensis,* come second; grape-fruit, *C. grandis,* is but rarely attacked.

Further examples of epiphylaxis are found in the leaves, stems and bracts of the American Upland cotton, *Gossypium hirsutum* L., which are covered with short hairs that protect the growing plant. Sea Island cotton, *G. barbadense* L., and Egyptian cotton, *G. peruvianum,* possess no such protective covering. In South Africa, American Upland cotton has been found capable of resisting the ravages of the Jassid, *Empoasca facialis* Jacobi, whereas Sea Island and Egyptian cottons were the first to be attacked. Lloyd Worrall[8] also found a great difference in the protective character of the various Upland varieties, some having only a few scattered hairs whilst others were hirsute. Even within a given variety, certain strains possessed more protective characters than the average plant typical of that variety. When individual plants were seen to remain resistant when neighboring plants were badly attacked, in every instance these individuals were found to be covered with dense hairs on leaf, stem and bracts. Hairy types of cotton are not totally immune from injury due to Jassid attack, but in large measure they resist the insect to such a degree that the plant is enabled to mature its bolls before it is seriously injured.

Other plants possess similar agencies capable of

[1] J. W. McColloch, "The Resistance of Plants to Insect Injury," *Biennial Report of Kansas State Hortic. Soc.*, Vol. 37: pp. 196–208, Topeka, Kansas, 1924.

[2] A. H. Lees, "Insect Attack and the Internal Condition of the Plant," *Ann. App. Biol.*, Vol. 13, No. 4, pp. 506–515, Cambridge Univ. Press, 1926.

[3] R. C. Treherne, "The Natural Immunity or Resistance of Plants to Insect Attack," *Agric. Gaz., Canada,* Vol. 4, No. 10, pp. 855–859, Ottawa, 1917.

[4] R. A. Wardle and P. Buckle, "The Principles of Insect Control," Chapter 1, "Host Resistance," pp. 1–16, Manchester, 1923.

[5] The breeding of plants to resist either disease or insect attack has not been discussed in this paper, but is of the utmost importance. See McColloch, Wardle and Buckle, *loc. cit.*, and Babcock and Clausen, "Genetics in Relation to Agriculture," pp. 444–463, New York, 1927.

[6] "Cotton Stainers and Certain Other Sap-feeding Insect Pests of the Cotton Plant. A Preliminary Inquiry into the Effect of Climatic and Soil Conditions upon the Incidence of these Pests." 8vo, 79 pp., 14 pp. refs., London, Empire Cotton Growing Corporation, January, 1926, *Rev. App. Entom.*, Vol. 14, Ser. A., pp. 461–462, London, 1926.

[7] E. P. Mumford and D. H. Hey, "The Water-Balance of Plants as a Factor in their Resistance to Insect Pests," *Nature,* Vol. 125, No. 3150, pp. 411–412, March, 1930.

[8] L. Worrall, "Jassid-resistant Cottons," *Jl. Union S. Africa Dept. Agric.*, Pretoria, Vol. 7, No. 3, pp. 225–228, September, 1923; Vol. 10, No. 6, pp., 487–491, June, 1925.

resisting the attacks of insect pests—for example, the thickness of the epidermis prevents some aphids, *Aphis maidis* Fitch, from attacking teosinte, *Euchloena mexicana*. Thick-skinned varieties of apple are not so readily attacked by the apple maggot, *Rhagoletis pomonella* (Walsh). This has also been shown to be true of the papaya fruit-fly, *Toxotrypana curvicauda* Gerst., and the melon-fly, *Bactrocera (Dacus) cucurbitae* (Coq.), on melons.

Examples of endophylaxis.—Although the external covering of the plant is all important as a protection against the invasion of pathogenic bacteria and fungi, which are often admitted by the punctures caused by insects, factors included under the term endophylaxis are probably more efficient in affording protection against sap-feeding insects.

During a recent visit to Honolulu, the writer had the opportunity of examining ten representative samples of wood which had been buried in the ground with a view to testing their relative resistance to termites, *Coptotermes formosanus* Shir.[9] There seemed to be little doubt but that the hard woods were attacked as freely as the soft woods, and the examination suggested that it was chemical, rather than physical, factors which made certain woods resistant.

A high ratio of potash to phosphoric acid in the leaves of the tea plant, *Thea sinensis,* is said to increase their resistance to the attacks of the tea mosquito, *Helopeltis theivora* Waterh.[10] It has been found possible to make cabbage plants stronger and more resistant to the attacks of cabbage fly, *Phorbia brassicae* (Bouché) by the addition of sodium nitrate or ammonium sulphate to the surrounding soil. At the Kansas State Agricultural College, increased resistance of wheat to the Hessian fly, *Phytophaga destructor* (Say.), has been secured by the addition of sodium nitrate to the cultural solutions. Russian investigators have found that a high silica content in the cells of *Lithospermum arvense* offers some protection against aphids.

Comes[11] considers that, *ceteris paribus,* the receptivity to parasites in a given organ increases with the quantity of reducing sugars, and that resistance increases with the organic acids. As the quantity of reducing sugars, so much sought after by insects, increases in vegetable tissues, there is, according to Comes, a corresponding decrease in the organic acids. Acidity, he considers, is the plant's defense against its enemies.

Further researches may also show some connection between the resistance of plants to insect pests and the physico-chemical properties of their cell-sap. Studies should be made of the hydrogen-ion concentration, water-content, osmotic pressure and electrical conductivity of the cell-sap and their possible correlation to the resistance or susceptibility of plants to the attacks of sap-feeding insect pests.

Carter[12] has made an important advance in his work on the relation between the osmotic pressure of the plant sap and the relative susceptibility of plants to attack by his discovery that the sugar-beet leafhopper, *Eutettix tenellus* (Bak.), avoids extremely high sap concentrations if more suitable food is available. In a small area where two growth-forms of the same species were present, the higher concentration forms were found to be abandoned for those having a lower centration. Similar studies have recently been made on the sap of sugar beets,[13] but the relation of these to Carter's interesting researches has not yet been determined. The plants studied by Carter were *Atriplex rosea* and *Salsola* sp. Investigations have also been made into the physiological basis of the varying susceptibility of sugar-canes to the froghopper, *Tomaspis saccharina* Dist., in Trinidad.[14,15]

Other examples which might possibly be included under the term endophylaxis occur in the copious secretion of resin which floods the larval galleries, drowning the young larvae, when sal trees, *Shorea robusta,* are attacked by the borer, *Hoplocerambyx spinicornis* Neum., and in the exudation of a milky juice by the delicate latex hairs of lettuce plants at Singalong. This latex fastens the insect to the plant.

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[9] D. T. Fullaway, "Termites or White Ants in Hawaii," *Hawaiian Forester and Agriculturalist,* Vol. 23, No. 3, pp. 68–88, Honolulu, 1926.

[10] E. A. Andrews, "Factors Affecting the Control of the Tea Mosquito Bug, *Helopeltis theivora* Waterh.," Ind. Tea Assoc., London, 1923.

[11] O. Comes, "La Profilaxia en Patoligía Vegetál," Reale Instituto d'Incorraggiamento di Napoli, 173 pp., Naples, 1916. *Bol. Agric. Técnica y Económica,* Vol. ix, No. 102, pp. 508–514, Madrid, June, 1917. Abstract in *Rev. App. Entom.,* Ser. A, Vol. 6, pp. 55–56, 1918.

[12] W. C. Carter, "Population of *Eutettix tenella* (Bak.) and the Osmotic Concentration of its Host Plants," *Ecology,* Vol. 8, No. 3, pp. 350–362, Brooklyn, N. Y., July, 1927.

[13] E. P. Mumford, "On the Curly-top Disease of the Sugar Beet; a Biochemical and Histological Study. Summary of Results," *Ann. App. Biol.,* Vol. 17, No. 1, pp. 28–35, 6 refs., 2 plts., Cambridge, February, 1930.

[14] E. P. Mumford, "Notes on the Froghopper Blight of Sugar Cane in Trinidad," *Bull. Ent. Res.,* Vol. 17, Pt. 2, pp. 139–150, 47 refs., London, October, 1926; (abridged as) "The Froghopper Blight," *West. Ind. Comm. Circ.,* Vol. 41, Nos. 714–715, pp. 49–50 and 73–74, 7 refs., London, 1926. *Rev. App. Entom.,* Vol. 14, Ser. A, Pt. 12, p. 619, London, 1926. "The Sugar-cane Froghopper," *West Ind. Comm. Circ.,* Vol. 40, No. 711, pp. 525–526, London, December, 1925.

[15] C. L. Withycombe, "Studies in the Aetiology of Sugar-cane Froghopper Blight in Trinidad, I. Introduction and General Survey," *Ann. App. Biol.,* Vol. 13, No. 1, pp. 64–108, Cambridge, February, 1926.