are undeniably a great contribution to botanical literature.

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SPECIAL ARTICLES

THE CYTOLOGY OF VEGETABLE CRYSTALS

WHILE studying the mucilage cells of cacti, chiefly *Opuntia* spp., I noted the occurrence of calcium oxalate druses both in these cells and in the ordinary parenchyma cells of pith and cortex. The wording of my description[1] exposes me to criticism as to the correctness of my observations, if Professor Jeffrey's views, as expressed in a recent issue of this journal,[2] are found to be well founded. As to this, however, I venture to express doubt, and therefore oppose my own observations to those of Professor Jeffrey.

He states that in "ginkgo," the "Juglandaceæ, Cactaceæ, Begoniaceæ, Geraniaceæ, etc.," the druses (spheroidal aggregates of calcium oxalate crystals) are formed by the laying down of "crystals . . . about the nucleus, when the protoplasm of the element is still dense and unvacuolated." "The crystals in fact constitute a spiny casing which surrounds the nucleus and protoplasm." "The nucleus is therefore central to the crystal itself. Corresponding to this fact there is only one druse in each cell." My own observations lead me to the following results:

The growing buds of ginkgo are indeed very favorable material, the young leaves especially. I have had no difficulty in finding young cells in which minute druses, in diameter less than one third that of the nuclei, could be seen lying in the protoplasm, there being at this time only small sap vacuoles, or none. If a vacuole is present, the druse is usually not found lying free within it and I think it doubtful if a druse ever originates in the sap vacuole, free from the protoplasm. On this point it must be conceded that the current texts do not speak convincingly, while some of the illustrations (*e. g.*, Frank's, see Stevens, "Plant Anatomy," p. 206) are, I think, a bit too diagrammatic, if not fanciful. As the druse increases in size it may come to occupy the greater portion of the total volume of the cell, when the nucleus may be seen crowded against the cell wall and between projecting crystals of the druse. There may then be no sap vacuole recognizable, the druse being clothed with dense protoplasm, with the nucleus as described. Later, in many cases, the protoplasm disappears so that a large druse may then be seen surrounded only by a thin cell wall which has never acquired the thickness of the walls of the living neighboring cells, and which also separates from them more or less. On treatment with hydrochloric acid, the middle of the druse is dissolved more readily than the peripheral larger crystals, and if the action of the solvent is stopped, so as to make the identification of the druses still unequivocal, one can then see some granular material, derived, I believe, from the druse, but which does not stain as protoplasm. Sometimes small flocks of material, staining as protoplasm, may be seen, probably relict of the once living protoplast. I conclude that there is some colloidal material imprisoned within the druse, and this may be essential in conditioning the growth of a crystal aggregate—as the mucilage of raphide cells may do also—but that this colloidal material is the protoplast occupying the central portion of the druse I deny. Accordingly, it is no matter of surprise to find two druses in a cell—though Professor Jeffrey appears not to have found this to be the case. This happens occasionally in narrower cells, in which the nucleus may be seen; it may happen ensconced between two druses. These latter may be of the same, or different—even widely different—sizes. When very small, the projecting crystals may not be easily distinguishable.

The granular, colloidal material above referred to can be seen in many of the larger druses even before treatment with acid, and appears to have a more or less radiating form. This it may be is the material regarded by Buscalioni (*vide* Tunmann, "Pflanzenmikrochemie," p. 139) as mucilaginous.

At any rate the presence of some such material within or intimately associated with the crystalline mass has already been observed; but whether there is a specific body which

[1] *Amer. Journ. Bot.*, 6, 156-166, April, 1919.

[2] E. C. Jeffrey: "The Cytology of Vegetable Crystals," SCIENCE, N. S., 50, 566-567, May 26, 1922.

serves as a center of crystallization is an open question. I have found examples of druses which display both radial and superficial symmetry of structure, centering upon a stainable mass, which, by virtue of these features, strongly incline one to attach importance to an idea of organization which, however, lacks the support of general observability and so becomes insubstantial. It is certainly probable that *something* furnishes a "nucleus" (I here use the physical term) for radial crystallization. The most frequent origin of the druse is in the cytoplasm, and it would appear that in the absence of such a "nucleus," a minute vacuole containing oxalic acid would serve, if calcium were available. It is infrequently that one finds a druse free in a large vacuole, however, and one inclines to the former view, especially when the structure of "rock candy" is recalled, and the string which serves as the "nucleus" for crystallization. Even when druses are formed in cells with very extensive vacuolization, such as the mucilage cells in the cacti, one finds most usually that they are held in the cytoplasm, and do not lie free in the vacuole. It is therefore rather more than likely that, when this does occur, it is secondary, the druse having been thrown out into the vacuole.

Professor Jeffrey further points out as a "surprising fact" that under the influence of the protoplast included within the druse the cell wall grows in size to accommodate the growing crystal. In opposition I venture to submit my observation that the shape of the druse is within limits determined rather by that of the enclosing cell wall, and can show preparations in which long crystals have grown into the more roomy end of the cell, while only short ones are found where their ends would more quickly impinge upon the cell wall. When cells which have died are observed, the cell wall, which, as above said, is thin, separates from the adjoining cell walls and collapses more or less, thus coming to form a closer investiture, conforming to a greater or less degree to the contour of the crystalline surface. Definitively, protoplasm has disappeared, and with its crystal ceased. But assuming the fact to be such as Professor Jeffrey asserts, his call of disappearance, growth in the cell wall and attention to the serious problem of the growth of the cell wall removed from immediate contact with the protoplast seems supererogatory. The variously elaborate investitures of spores and analogous bodies supply examples of such difficulty which the mechanistic mind can not, nor, I believe, desires, to minimize.

I have spoken above only of ginkgo. I find, however, nothing in the Cactaceæ, Orchidaceæ, Iridaceæ, Begoniaceæ or in any other material at all out of harmony with what I have found there. In the begonias, in particular, one may find in the calcium oxalate containing cells not merely druses, but various conditions ranging to single crystals. Although it is well known that "inclusions" may occur in crystals, such would be easily enough demonstrable. Here it may be added that by breaking open the large druses, cytoplasmic inclusions if present would be readily exposed to stains. But preparations made in this way, as well as by partial solution by acids, have equally yielded nothing to substantiate the views of Professor Jeffrey.

Of course, any attempt to discuss the problem of the origin and mode of growth of crystals in living cells would involve many more facts than those connected merely with the druse; and the particular contribution of the living substance is the matter above all in which we are interested. In spite of the implications of Professor Jeffrey's concluding remarks directed at the mechanists, it still remains legitimate to use what we do know to attempt to explain what we do not. For example, it is permissible to argue that the mucilage of raphide cells, because of its emulsoid character, furnishes a suitable nidus for the growth of acicular crystals, and it is quite possible that appropriate experiments *in vitro* would show that such crystals can be produced thus. The exceedingly long raphide cells in the petals of *Œnothera* suggest strongly that a capillary glass tube filled with a suitable emulsoid might furnish the mechanism required, but until some one succeeds in doing this, we may permit ourselves to marvel at the living mechanism, so long only, however, as this attitude does not paralyze experimental effort.

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