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The Low Calcium Content of Cellular Systems Adapted to Flow

Recently EPSTEIN[1] stressed a few wellknown facts about the phloem and put forward a tentative explanation for their correlation with the observed very low calcium and boron content. In relation to these suggestions – which I would like to endorse – there seem to be a number of other rather interesting points and correlations which could be added to expand the view.

Phloem is not the only living plant tissue adapted to flow. If wounded, the latex system of many plants will show extensive flow. Especially the outflow of latex from *Hevea brasiliensis* has been extensively investigated. This latex is derived from a large drainage area and is extruded by means of osmotic attraction of water[2]. The exuding latex can best be considered as a diluted cytoplasm[3], as it contains both many proteins and plastids and an enormous array of enzymes. The low viscosity of latex is again linked with its very low calcium content, e.g. ca. 2% of the total cation content[4].

This low calcium and high potassium content of both phloem and latex plasm would seem to be appropriate from the point of view of plasmatic viscosity. Monovalent ions cause swelling and lowered viscosity, while divalent ions favour an increased viscosity due to lower water content. The fluidity of latex can be related to a certain amount of swelling. In the ontogeny of the latex vessels in *Hevea* the cytoplasm increases in volume, while the original large vacuoles retract to a multi-disperse system of minute droplets[3,5]. The resulting immense number of lutoids[6] ultimately only occupy a few percent of the volume of exuded latex. Also the electron microscope has produced evidence of the strong dilution of the phloem cytoplasm.

EPSTEIN[1] proposes an exclusion of calcium from the sieve tubes. The question arises as to where we must locate this process of restricting calcium activity. One could conceive of relating it to the process of vein-loading. But there is also a possibility of a low supply towards the phloem from cells with a low calcium activity.

In the conception 'symplasm', the unity of cytoplasmic contents of living cells, connected by their plasmodesmata and including the phloem, is implied. From this point of view of cytoplasmic continuity there is reason to suspect a low calcium activity in the cytoplasm of surrounding cells as well. This would seem to be contrary to the generally moderate to high calcium content of most cells, but much of it is located in cell-walls or vacuoles. That much of the calcium in the plant could be non-essential has also been suggested by WALLACE, FROHLICH and LUNT[7]. Although cell-organelles, e.g. chloroplasts can accumulate calcium, some recent evidence from muscle physiology suggestsvery low calcium activities[8–10]. For *Nitella translucens* a value of 8 m*M* in the flowing cytoplasm is mentioned[11], while for *Nitella flexilis* a value of 125 m*M*/l is given for potassium[12].

In approximate values, the following K/Ca ratios can be given as an illustration:

Nitella	15	*Ricinus* sprout	3
Yucca phloem exudate	120	*Ricinus* phloem exudate	400
Hevea latex	200		

This low calcium content, especially in the sieve tubes, has been investigated more closely. A high phosphate concentration and high pH have already been suggested as restricting calcium solubility. Recently VAN GOOR[13], at our Institute, has obtained evidence that the phloem exudate will hardly accept even very small additions of calcium. Very soon after the first minute additions, turbidity occurs, indicating precipitation. Thus the low soluble calcium content is near its ultimate limits. The governing factors, besides the pH of ca. 7.5, are thought to be high content in (organic) phosphates and the numerous organic acids.

Thus we come to consider the living transport system of the plant as able to contain only small concentrations of soluble calcium. This is the result of the necessity to transport important components to supply the growth centres. Relevant factors in this respect are the metabolically important phosphates and the large amount of organic anions. These organic anions – originating from nitrate reduction – and mainly coupled to the important potassium ion[14], could explain the high pH.

Résumé. La basse teneur en calcium et la haute teneur en potasse du latex et du suc de phloème sont en relation avec une faible viscosité, condition nécessaire à une certaine fluidité. Il semble que la concentration du calcium dans le cytosol des cellules normales est également très basse, comme on peut s'y attendre quand il s'agit d'un «symplasma». La teneur très basse en calcium dans le phloème peut être mise en relation avec la teneur très élevée en phosphates, le pH élevé et la présence de beaucoup d'acides organiques.

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