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McNally S F, Hirel B, Gadal P, Mann A F & Stewart G R. Glutamine synthetases of higher plants. Evidence for a specific isoform content related to their possible physiological role and their compartmentation within the leaf. *Plant Physiol.* 72:22-5, 1983.
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This paper demonstrated that plant leaves exhibited marked differences in stoichiometry of cytosolic and chloroplastic forms of glutamine synthetase. The absence of cytosolic glutamine synthetase from the leaves of several species active in photorespiration suggested the reassimilation of photorespiratory ammonium occurred via chloroplastic glutamine synthetase and not the cytosolic isoform. [The *SCI*® indicates that this paper has been cited in more than 110 publications.]

Glutamine Synthetase Isoforms of Higher Plants

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In 1974, the discovery of glutamate synthase in plant tissues dramatically changed our ideas regarding the pathway of ammonium assimilation.[1] This transformed glutamine synthetase from a rather mundane enzyme that synthesized the storage compound glutamine into a key enzyme of plant nitrogen metabolism. The *Citation Classic* article brought together two research groups that had discovered, more or less simultaneously, isoenzymes of glutamine synthetase in plant tissues.[2,3] Shortly after, I moved to Birkbeck College, University of London, where the Agricultural and Food Research Council generously supported research into the occurrence and role of glutamine synthetase isoforms. Here, Sheila F. McNally joined me as a postdoctoral student.

At a meeting of the Society for Experimental Biology, a group from Orsay, France, and our group recognized the similarity of our talks, and we decided to publish a joint paper. This marked the beginning of the most productive period of research I can remember, and it led to the development of many close friendships.

We were able to show that plant species differed with respect to the occurrence and relative amounts of glutamine synthetase. We found that four groups of plants could be recognized on the basis of differences in the stoichiometry of the isoforms in leaf tissue. One of the most important findings was that many plants with C3 photosynthesis lacked the cytosolic isoform of glutamine synthetase. In contrast, most of the C4 species that we examined had a high content of the cytosolic isoform. The importance of this lay in the proposal from the Rothamsted group that photorespiratory ammonium was reassimilated via cytosolic isoform.[4] Our results ruled this out for many species, leaving a role in the photorespiratory nitrogen cycle for chloroplastic glutamine synthetase. Ironically the most decisive evidence confirming our hypothesis came from mutants of barley isolated by the Rothamsted group that lacked chloroplastic glutamine synthetase and could only grow under conditions that suppressed photorespiration.[5]

The paper is frequently cited because it provides a comprehensive account of the occurrence of glutamine synthetase isoforms in plants having different physiological and ecological characteristics. However, the main reason for its success is the rise of plant molecular biology. In the 10 years since this study, our original biochemical findings have been developed at the molecular level by a number of groups,[6] including B. Hirel, now at Versailles. For me, one of the most impressive pieces of work at the molecular level was the use of a reporter gene to show the tissue-specific synthesis of the nodule isoforms in transgenic *Lotus*.[7]

My personal feeling about this paper is that it illustrates how rewarding collaborative science can be—the synthesis of two groups' findings proved more scientifically significant than if we had published independently. Certainly the subsequent collaborative work that we pursued proved no less rewarding—scientifically, gastronomically, and enologically.

1. **Lea P J & Miflin B J.** An alternative route for nitrogen assimilation in higher plants. *Nature* 251:614-6, 1974. (Cited 255 times.)
2. **Guiz C D, Hirel B, Shedlovsky G & Gadal P.** Occurrence and influence of light on the relative proportions of two glutamine synthetases in rice leaves. *Plant Sci. Lett.* 15:271-7, 1979. (Cited 70 times.)
3. **Mann A F, Fentem P A & Stewart G R.** Identification of two forms of glutamine synthetase in barley (*Hordeum vulgare*). *Biochem. Biophys. Res. Commun.* 88:515-21, 1979. (Cited 105 times.)
4. **Keys A J, Bird I F, Cornelius M F, Lea P J, Wallsgrove R M & Miflin B J.** Photorespiratory nitrogen cycle. *Nature* 275:741-2, 1978. (Cited 235 times.)
5. **Wallsgrove R M, Turner J C, Hall N C, Kendall A C & Bright S W J.** Barley mutants lacking chloroplast glutamine synthetase—biochemical and genetic analysis. *Plant Physiol.* 83:155-8, 1987.
6. **Forde B G & Cullimore J V.** The molecular biology of glutamine synthetase in higher plants. (Miflin B J, ed.) *Oxford surveys of plant molecular and cell biology*. Oxford, England: Oxford University Press, 1989. Vol. 5. p. 246-96.
7. **Forde B G, Day H M, Turton J F, Wen-jun S, Cullimore J V & Oliver J E.** Two glutamine synthetase genes from *Phaseolus vulgaris* L. display contrasting developmental and spatial patterns of expression in transgenic *Lotus corniculatus* plants. *Plant Cell* 1:391-401, 1989.

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