

Combating freshwater scarcity

Pushpangadan *et al.*¹ have 'offered the idea of discovering and exploiting water-fixing/harvesting/synthesizing organisms from desert organisms or thermophilic bacteria' for combating freshwater scarcity in plants. Their idea is based on the false notion that 'certain living organisms (both flora and fauna) grow and thrive well in sand dunes of deserts like Sahara, but certain thermophilic bacteria and some higher forms of life have also been located in the sand dunes'. Further, they write, 'Plants can thrive well in deserts or other places where there is no water'.

Let us first consider whether plants 'thrive' in deserts. This is best answered if the net productivity of vegetation in different ecosystems is compared. The mean amount of dry matter, measured as the number of grams per square metre per year in (i) extreme desert, (ii) semi-desert, (iii) tundra and alpine, (iv) tropical seasonal forest, and (v) tropical rainforest is 3, 90, 140, 1600 and 2200 respectively². The images of desert plants show these as succulent stems with few or no leaves³. The physiological and biochemical adaptations for survival in desert habitats must include complex changes in membrane structure and function, tissue-water content, global gene expression, and in the composition of lipid, protein and primary and secondary metabolites⁴.

Second, regarding the presence of thermophilic bacteria in desert soils, we may ask if their presence there results from their growth and reproduction *in situ* or from their dissemination from foci of growth elsewhere. For example, the occurrence of thermophilic bacteria in cold environments is well known⁵. The mixing and the widespread global distribution of both cold- and heat-loving bacteria in places where they are not expected could be due to oceanic water currents. According to the authors¹ 'a number of thermophilic bacteria have been obtained from hydrothermal vents... with temperatures of 375°C or above'. A reader gets the impression that this is the present upper temperature limit of life! However, the current record of the most thermophilic microbe is that of *Nanoarchaeum equitans*, discovered in an undersea hydrothermal vent off the coast of Iceland⁶. The maximum temperature of growth of this archaeon is 121°C, the temperature reached in a pressurized food cooker or an autoclave.

The point to note is that the hydrothermal microbial communities are not growing inside the chimney from which hot 'black smoke' emission occurs and inside which temperature could well be near or beyond 400°C. Rather, communities of bacteria are growing along the thermal gradient created by the mixing of hot effluent with ice-cold ocean water. Also, because of the hydrostatic pressure (greater than 1000 atm), the water in which communities of tube-like animals and symbiotic bacteria inside them⁷ or the chemolithotrophic bacteria are living, is not in the gaseous state. These bacteria have water available all the time, although the water is salty. Since they have evolved there, the bacteria are adapted to life in marine, thermophilic environment. The problem of thermophilic marine bacteria combating water scarcity therefore does not arise.

Even the hardiest of plants do require liquid water, at least for a limited period, for absorption of nutrients in the dissolved form. Based on the misconception that hyperthermophilic bacteria in deep-sea hydrothermal vents suffer water scarcity. Pushpangadan *et al.*¹ call attention to the 'Knall-gas reaction' ($O_2 + 2H_2 \rightarrow 2H_2O$) involving hydrogenase. Chemolithotrophic marine bacteria oxidize hydrogen ($H \rightarrow H^+ + e$) using hydrogenase to generate an electrochemical gradient for the production of ATP and NADP(H), rather than for producing water⁸. The genetic engineering of plants proposed by Pushpangadan *et al.*¹ for combating water scarcity should take into account the wide temperature difference in growth of (cultivated) plants (max ~48°C) and of thermophilic bacteria (max 80–121°C). Therefore, a hydrogenase of a hyperthermophile, genetically engineered in plants, is expected to be conformationally too rigid and a poor catalyst at the temperature at which the majority of plants grow (increase in dry matter), i.e. 25–40°C. In a living cell, there are metabolic reactions in which water is a by-product as well as a reactant. To be beneficial, the genetic engineering that the authors have in mind must result in the net gain of freshwater from the metabolically-produced water, since the terrestrial plants must also confront the evaporative loss due to transpiration. Moreover, in terrestrial plants, water stress is associated with temperature stress; the latter alone

causes profound changes in metabolism. In summary, although the 'fast-depleting freshwater resources of the planet' are a matter of concern, and one may be delighted to see the role of thermophilic microorganisms being championed for innovative biotechnology for combating water scarcity, thermophilic bacteria are no exception to the dictum that no liquid water, implies no life.

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RAMESH MAHESHWARI

*Department of Biochemistry,
Indian Institute of Science,
Bangalore 560 012, India
e-mail: fungi@biochem.iisc.ernet.in*

Response:

I noted with interest the correspondence by Maheshwari on our article¹ which was a response to the commentary by B. P. Radhakrishna on man-made drought and the looming water crisis². My brief response to Maheshwari is as follows.

1. Our idea is not based on any false notion, it is only a logical idea that we put forward. We all know that the extreme desert areas are rarely devoid of life and microorganisms, and certain plants and animals are still found surviving in harsh conditions. Maheshwari mistook our expression 'grow and thrive' to perhaps a thriving ecosystem and described the net

productivity of vegetation and made a comparison of the same under ecosystems. We have neither indicated that the net productivity of the desert is in any manner high nor compared it with any dry matter measurement of any ecosystem. We mentioned 'that certain living organisms (both flora and fauna) grow and thrive well in sand dunes...'. Grow and thrive should not be interpreted as thriving vegetation or faunal life in the desert. We have also mentioned that the succulent plants of the deserts have a crassulacean acid metabolism of photosynthesis, which separates CO₂ absorption and its actual fixation in time. There are also data available to show that seed densities average between 5000 and 10,000 per m² in the Sonoran

desert, USA and up to 20,000 per m² in the Sahara desert. (Deserts USA Newsletter: www.desertsusa.com/du_plantsurvive.html).

2. Water is a limiting factor for life, but life forms (odd bacteria algae) have been detected under the harshest conditions.

3. Regarding Maheshwari's comments on hydrogenase, he may refer to Reysenbach, A.-L. and Shock, E., *Science*, 2002, **296**, 1077–1082.

4. However, we appreciate the closing remarks of Maheshwari that '...although the "fast-depleting freshwater resources of the planet" are a matter of concern, and one may be delighted to see the role of thermophilic microorganisms being championed for innovative biotechnology for

combating water scarcity, thermophilic bacteria are no exception to the dictum that no liquid water implies no life'.

1. Pushpangadan, P., Srivastava, S., Mehrotra, R. and Kochhar, V. K., *Curr. Sci.*, 2004, **87**, 1644–1646.
2. Radhakrishna, B. P., *Curr. Sci.*, 2004, **87**, 20–22.

P. PUSHPANGADAN

*National Botanical Research Institute,
Rana Pratap Marg,
Lucknow 226 001, India
e-mail: pushpangadan@satyam.net.in*

Bioengineering in biological control: Prospects and progress

Agricultural systems provide adequate opportunities for studies on herbivore-induced volatile organic compounds which influence herbivore location behaviour by natural enemies, enabling sizable reduction of herbivores. The intimate interaction between plants and natural enemies is known to act as a driving force leading to the production of adequate signals affecting the behaviour of natural enemies in a positive way¹. With increasing awareness of the role of signal molecules in insect communication, attempts at biosynthesis of these molecules are gaining increased recognition by entomologists and plant pathologists engaged in the study of insect-plant interactions. Biosynthesis of these signal molecules has led to increased understanding of the utilization of these signals in the behavioural, physiological and morphogenetic responses of insects. With nanogram samples of these messenger molecules, it has become possible to isolate components from mixtures, enabling characterization of unknown natural products. The biosynthesis and isolation of compounds have become significant as in the understanding of the role of mono- and sesquiterpenes in the attraction of natural enemies^{2,3}. Prospects of bioengineering them efficiently enabling plants to produce these compounds which attract an array of natural enemies are on the increase. The primary role of natural products is to enable plants to communicate with the en-

vironment, acting as toxins or biocides against insect and other plant species, besides acting as stress signals activating plant defence. Incidentally mention may be made of transgenic plants in which the metabolic engineering of cytochrome P 450 has resulted in improved insect resistance⁴.

It is now known that many compounds released after herbivore damage are common to more than one species, while others are species-specific. While the green leaf volatiles or C₆ alcohols, and phenolics such as methylsalicylate are often detected, what has become more important is an assessment of the elicitor molecules in the oral secretion of herbivores. Two well-known compounds introduced by insect feeding are β-glucosidase and volicitin, the former from the regurgitant of *Pieris brassicae* caterpillar and the latter from *Spodoptera exigua*^{5,6}. Since different herbivore feeding can induce different blends of volatiles, the need for identifying the large number of yet unknown compounds in oral secretions cannot be overemphasized. Interestingly enough, β-glucosidase triggers the same volatile release as feeding by the larvae. In the case of volicitin, a fatty acid-amino acid conjugate, its potency as an elicitor of maize isolates which attract parasites, is well documented. The wounding of plant tissues also results in the triggering of the octadecenoid pathway, resulting in the release of jasmonic acid⁷, which serves as a signal for the expres-

sion of a number of compounds that contribute to plant resistance, besides activation of the oxidative burst involving polyphenol oxidases. As such the volatile blend to be introduced or enhanced should be chosen to closely match the major attractants known for the natural enemy species against which control has to be initiated. The need for synchronizing the release of terpene volatiles with the presence of herbivores is important, so that when modifying existing volatile release in a crop plant, the need for a herbivore promoter also becomes relevant.

While the genes encoding the biosynthetic steps are engaging the attention of molecular biologists, manipulation of the steps involved in the communication of C₅ units in the basic pathways such as the mevalonate pathway, becomes necessary. While the pathways are well known, precursors of terpene biosynthesis are now identified as geranyl diphosphate (for monoterpenes) and farnesyl diphosphate (for sesquiterpenes). Genes encoding both have been identified, the enzyme terpene synthesis converting them with mono- and sesquiterpenes. Needless to emphasize that it is the engineering of terpene synthesis that provides numerous opportunities to alter specific composition of terpene volatiles⁸. With these new and recent developments, the feasibility of engineering crop plants to emit readily detectable burst of terpenes to signal the presence of herbi-