Qualitative Evidence for Expression of \textit{Klebsiella pneumoniae nif} in \textit{Pseudomonas putida}

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\textit{Pseudomonas putida} MT20-3 carrying the \textit{Klebsiella pneumoniae nif} plasmids pRD1 or pMF250 showed highly O$_2$-sensitive aerobic acetylene reduction on low-N pyruvate or glucose agar. This finding confirms unequivocally that \textit{K. pneumoniae nif} can be expressed in an obligate aerobe.

INTRODUCTION

The ability of members of the genus \textit{Pseudomonas} to fix nitrogen, long subject to uncertainty (see discussion by Postgate et al., 1987), was finally established by the report (Barraquio et al., 1986) of O$_2$-sensitive diazotrophy in \textit{P. saccharophila}. The ability of genetic constructs of \textit{Pseudomonas} to express the \textit{nif} gene cluster of \textit{Klebsiella pneumoniae} has also been doubted. Mergeay & Gerits (1978) obtained transconjugants of a putative \textit{P. fluorescens} carrying IncP or IncF plasmids bearing the \textit{K. pneumoniae nif} cluster which reduced acetylene aerobically in stagnant culture. Their report had disquieting features because (a) the \textit{Pseudomonas} had originally been isolated as a Rhizobium and (b) the IncF plasmid FN68, which is usually unstable, was accepted and expressed in this organism. Lehtinen & Mäntsälä (1981) found that the more stable IncP \textit{K. pneumoniae nif} plasmid pRD1 was unstable in \textit{P. fluorescens} but obtained three strains of \textit{P. putida}(pRD1) which, however, did not reduce acetylene in anaerobic or aerobic conditions. They did not state the precise nature of their 'aerobic' conditions but they confirmed the presence of pRD1 in their derivatives by mating \textit{P. putida}(pRD1) to \textit{Escherichia coli} and demonstrating nitrogenase synthesis in the recipients. The question is important because, with the withdrawal of a claim that these genes are expressed in \textit{nif} mutants of \textit{Azotobacter vinelandii} (Cannon & Postgate, 1983), there is no clear evidence for their expression in an obligately aerobic host.

We now report unequivocal acetylene reduction by \textit{P. putida} carrying plasmid-borne \textit{K. pneumoniae nif}. The process is extremely O$_2$-sensitive in \textit{P. putida} and satisfactory quantitative data are not available. This finding was briefly mentioned by Postgate et al. (1987).

METHODS

Organisms and culture. Organisms and plasmids are listed in Table 1. \textit{P. putida} MT20-3 (Williams & Worsey, 1976) is a his derivative of \textit{P. putida} WW20 which was cured of its To1 plasmid pWW20. The \textit{nif} plasmid pMF250 is a descendant of RP4 via pRD1 (= RP41; Dixon et al., 1976) and pMFlOO (Merrick et al., 1980) with the original drug resistance genes deleted and Km' restored with Tn5. Plasmids were normally resident in \textit{E. coli} JC5466 except for pWW20 which is naturally resident in \textit{P. putida} MT20 and its derivatives. Bacteria were grown aerobically at 29 °C on minimal glucose agar (Davis & Mingioli, 1950) with 30 µg tryptophan ml$^{-1}$ for \textit{E. coli} with 30 µg histidine ml$^{-1}$ for \textit{P. putida} MT20-3. \textit{E. coli} was sometimes grown at 37 °C; \textit{P. putida} MT20-3 did not grow at 37 °C. For mating, loops of donor \textit{E. coli} and recipient \textit{P. putida} were spread with 1 or 2 drops of saline phosphate buffer (SP; Krishnapillai & Postgate, 1980) on Luria's agar (LA; Kennedy, 1977) and incubated for 18 to 24 h at 29 °C. Cells resuspended in SP were spread on glucose minimal agar with 15 µg kanamycin ml$^{-1}$. To enable transfer of IncQ plasmids to \textit{P. putida}, donor \textit{E. coli} JC5466 derivatives were

\textbf{Abbreviations:} SB, saline phosphate buffer; LA, Luria's agar; NB, nutrient broth.

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Table 1. Bacteria and plasmids

<table>
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<tr>
<th>Bacterial strains</th>
<th>Genotype</th>
<th>Origin or reference</th>
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<tr>
<td><em>Pseudomonas putida</em> MT20-3</td>
<td>his</td>
<td>P. A. Williams, University of Bangor, UK</td>
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<tr>
<td><em>Escherichia coli</em> JC5466</td>
<td>his trp recA rplE</td>
<td>N. Willets</td>
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Plasmids

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<tr>
<th>Plasmid</th>
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<tr>
<td>pWW20</td>
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<td>P. A. Williams</td>
</tr>
<tr>
<td>pRD1</td>
<td>Cb Km Tc Gnd Nif His ShiA Tra IncP</td>
<td>Dixon et al. (1976)</td>
</tr>
<tr>
<td>pMF250</td>
<td>Km Gnd His ShiA Tra IncP</td>
<td>M. Filser, see Postgate &amp; Kent (1985)</td>
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<tr>
<td>pCK1</td>
<td>Sm Mob Km:nifA:Km IncQ</td>
<td>Kennedy &amp; Robson (1983)</td>
</tr>
<tr>
<td>pRK2013</td>
<td>Sm Tra</td>
<td>Figurski &amp; Helinski (1979)</td>
</tr>
<tr>
<td>pMD45</td>
<td>Sm Mob Km:ntrC:Km IncQ</td>
<td>Kennedy &amp; Drummond (1985)</td>
</tr>
<tr>
<td>pMM22</td>
<td>Sm Mob Km:ntrA:Km IncQ</td>
<td>M. Merrick, University of Sussex, UK</td>
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constructed carrying both the IncQ plasmid and the Tra+ mobilizing plasmid pRK2013 (Figurski & Helinski, 1979). Presumptive transconjugant *Pseudomonas* isolates, selected with 100 μg streptomycin ml⁻¹, were checked for absence of donor by their failure to grow on LA at 37 °C. Plasmids in transconjugants were demonstrated by electrophoresis of alkaline lysates or boiled SDS extracts in agarose gels (Cannon, 1980) as appropriate; plasmid pWW20 was detected by Wheatcroft & Williams's (1981) method. Genetic evidence that the IncP plasmids retained relevant *Klebsiella* DNA in the new background was obtained by transconjugation from the *P. putida* derivatives to *E. coli* JC5466. Donor and recipient strains were mated in liquid NFDM (Cannon et al., 1974) supplemented with aspartate (100 μg ml⁻¹) and Oxoid nutrient broth (NB; 2.5%, w/v) (Postgate & Kent, 1985) for 24 h at 30 °C, the culture selected for KmrSpcr E. coli transconjugants and their Nif+ phenotype checked by acetylene reduction in similar NFDM + 30 μg tryptophan ml⁻¹.

RESULTS

Plasmids pMF250 or pRD1 transferred from *E. coli* JC5466 to *P. putida* MT20-3 at about 3 x 10⁻⁴ transconjugants per total cell population mated with 100% co-transfer of Km+ and His+.

Slopes of *P. putida* (pRD1) or (pMF250) on glucose- or sodium pyruvate-based NFDM containing aspartate and NB, set with agar, were incubated in air until grown (18 to 24 h at 29 °C) and then sealed under N₂ with low O₂ (below). The cells grew as a thin film; they were clearly O₂-limited because growth was more abundant in air. Such cultures gave clear and qualitatively reproducible acetylene reduction after 2 to 5 d. All positive tubes were checked for absence of donor (see Methods); controls with wild-type *P. putida* were uniformly negative. A variety of formulations of the agar media was tested and, though the majority supported acetylene reduction in similar NFDM + 30 μg tryptophan ml⁻¹.

In an effort to obtain standardized quantitative replication, the procedure and conditions given in Fig. 1 were adopted for routine use but an unacceptable scatter of reduction rates and lags occurred among triplicate tubes. We attribute this scatter partly to inhomogeneity of bacterial growth on the agar, partly to imperfect replication of oxygen tensions in the system used. However, in no test did *P. putida* (pMF250) or (pRD1) reduce acetylene if sealed under pure O₂-free N₂, nor if NH₄Cl (0.2%, w/v) were present in the agar. No anaerobic growth of this strain occurred with nitrate or fumarate as electron acceptors for glucose, pyruvate or fumarate.
Fig. 1. Acetylene reduction on low-N agar slopes at low pO$_2$ by $P$. putida MT20-3(pMF250) and derivatives. Organisms from 24 h plates of glucose minimal medium were suspended to similar densities (OD$_{540}$ about 0.5) and inoculated in triplicate with a loop on 10 ml pyruvate–NFDM agar slopes in 30 ml tubes with kanamycin or kanamycin and streptomycin, as appropriate. After 7 h at 29 °C in air, tubes were tilted carefully to wet the whole agar surface. After 24 h in air, all tubes were gassed out aseptically with N$_2$, sealed with a Suba-seal closure and air injected to 0.004 atm O$_2$. After a further 21 h (time zero in the Figure), 1 ml C$_2$H$_2$ was injected. Selected tubes are illustrated of constructs carrying the nif plasmid pMF250 alone (○) or with pCK1 (■), pMD45 (□) or pMM22 (●) (see text and Table 1). Lags, turnover points and reduction rates were not consistent among triplicate tubes of the strains tested but all were qualitatively positive.

Constructs of $P$. putida(pMF250) were made carrying the plasmids pCK1 (nifA$^+$: Kennedy & Robson, 1983), pMD45 (ntrC$^+$: Kennedy & Drummond, 1985) and pMM22 (ntrA$^+$: M. Merrick, personal communication). None appeared better or worse than the parent (Fig. 1). The bacterial growth washed off six slopes, which had given clear, continuous acetylene reduction, into SP was assayed for protein by the Lowry method and specific activities were calculated. They were similar at about 0.3 nmol C$_2$H$_2$ formed (mg protein)$^{-1}$ min$^{-1}$ (cf. 70 to 180 for $K$. pneumoniae) but for one capricious tube of substantially higher activity which gave ordinary activity on subculture.

The Tol plasmid pWW20 carries the xylR gene which regulates the xylABC cluster. It does so via a promoter (OP1) which shows considerable homology to Ntr-activatable promoters of nif and other operons (see Dixon, 1986). However, slopes of $P$. putida MT20-3(pWW20, pMF250) showed no significant differences in acetylene-reducing activity from slopes of $P$. putida (pMF250). Induction of xylR by including methylbenzyl alcohol in the medium decreased rather than augmented activity.

O$_2$-sensitive aerobic acetylene reduction by $P$. putida(pMF250) growing dispersed in sloppy NFDM agar was mentioned by Postgate et al. (1987). That system had no advantage over agar for quantitative study. Considerable effort was made to obtain a homogeneous experimental system but no acetylene reduction by $P$. putida(pMF250) or (pRD1) was detected in numerous assays in liquid glucose or pyruvate–NFDM shaken gently in air, stagnant in air or stagnant in sealed vessels at initial pO$_2$ values ranging from 0.05 to 0.002 atm.

DISCUSSION

This work provides unequivocal evidence of aerobic expression of the $K$. pneumoniae nif cluster in a taxonomically defined aerobic Pseudomonas background. It confirms the claims of Mergeay & Gerits (1978) that nif from $K$. pneumoniae is expressed in the genus Pseudomonas and it indicates that there is no obstacle in principle to expression of this cluster in other aerobic physiological backgrounds. The extreme sensitivity of expression to O$_2$-repression or inhibition suggests that ideal conditions for expression of nif from $K$. pneumoniae were not obtained in this work and implies that respiratory protection in these constructs is minimal. The apparent failure
of constitutive ntrC, ntrA or nifA plasmids to influence activity probably reflects this fact. The results also show that P. putida possesses a chromosomal ntr-like system sufficiently analogous to the ntrA ntrBC system of K. pneumoniae to activate K. pneumoniae nif and, further, that xylR is not involved.

REFERENCES


