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Pyrroloquinoline Quinone, a Chemotactic Attractant for
Escherichia coli

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Escherichia coli is attracted by pyrroloquinoline quinone (PQQ), and chemotaxis toward glucose is enhanced by the presence of PQQ. A ptsI mutant showed no chemotactic response to either glucose or PQQ alone but did show a chemotactic response to a mixture of glucose and PQQ. A strain lacking the methylated chemotaxis receptor protein Tar showed no response to PQQ.

In Escherichia coli, the uptake of many sugars is catalyzed by the phosphoenolpyruvate-sugar-phosphotransferase system, PTS (15). In Klebsiella pneumoniae, another member of the family Enterobacteriaceae, glucose can also be metabolized after periplasmic oxidation by the pyrroloquinoline quinone (PQQ)-dependent glucose dehydrogenase, GLD (13). E. coli can synthesize the apoenzyme of GLD (3), but it is seemingly unable to synthesize PQQ (7, 8, 21). However, the enzyme can be easily reconstituted to a functional dehydrogenase by the presence of PQQ in the environment because its active center can synthesize the apoenzyme of GLD (3), but it is seemingly unable to synthesize PQQ (7, 8, 21). However, the enzyme can be easily reconstituted to a functional dehydrogenase by the presence of PQQ in the environment because its active center can be easily reconstituted to a functional dehydrogenase by the presence of PQQ in the environment because its active center.

In Escherichia coli, there are several sensory mechanisms that operate to control motility (19). Most research has been focused on a family of methylated chemotaxis receptor proteins designated Tsr, Tar, Tap, and Trg (19, 20). Responses to oxygen (aerotaxis) depend on the presence of the electron transport system (16). Chemotaxis toward glucose depends on the PTS (11, 15) in which enzyme II acts as a receptor (2, 11, 19). Chemotaxis of E. coli (strains given in Table 1) toward PQQ was investigated both by using swim plates and by the capillary assay (12). In all cases, cells were pregrown on mineral medium (MM) (per liter; 1 g of (NH₄)₂SO₄, 10.5 g of K₂HPO₄, 4.5 g of KH₂PO₄, 0.2 g of MgCl₂, 38 mg of EDTA, 15 mg of thiamine, and 0.9 mg of FeSO₄; carbon source, 0.5%; pH 6.8) with glycerol as the carbon source to ensure high GLD activities.

E. coli strain Relevant genotype Source and reference

Table 1. E. coli strains used

<table>
<thead>
<tr>
<th>E. coli strain</th>
<th>Relevant genotype</th>
<th>Source and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW405</td>
<td>ara-14 galK2 galT1 lacY1 mtl-1 xyl-5 hisG4 leuB6 thr-1(Am) thi-1 sup totA31/T5 tsx-78 epsL136; parental strain of AW518, AW539, and AW701</td>
<td>M. S. Springer (18)</td>
</tr>
<tr>
<td>AW518</td>
<td>tsr</td>
<td>M. S. Springer (18)</td>
</tr>
<tr>
<td>AW539</td>
<td>tar</td>
<td>M. S. Springer (18)</td>
</tr>
<tr>
<td>AW701</td>
<td>trg</td>
<td>H. Kondoh (10)</td>
</tr>
<tr>
<td>RP3525</td>
<td>tap</td>
<td>M. Sciocum (17)</td>
</tr>
<tr>
<td>Lin225</td>
<td>ptsI</td>
<td>P. W. Postma (unpublished strain)</td>
</tr>
<tr>
<td>PPA297</td>
<td>ged::cam</td>
<td>P. W. Postma (unpublished strain)</td>
</tr>
<tr>
<td>YMC10</td>
<td>endA1 thi-1 hsdR17 supE44 dlacU169 hutCklebs</td>
<td>Y. M. Chen (4)</td>
</tr>
</tbody>
</table>

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POQ, no activity could be detected, whereas the addition of POQ resulted in a swarm rate of 0.41 mm/h (± 0.03). This was not the case when fructose was used as the carbon source. The effect of POQ on the swarm rate of the wild type toward fructose (Table 2) therefore must have been caused by a POQ-sensing system. This was investigated using strains lacking one of the four known receptors, Tar, Trg, or Tsr and their parental strain on tryptone swarm plates with or without POQ. From the results shown in Fig. 1, it can be concluded that POQ was sensed by the aspartate receptor: the wild-type strain showed increased chemotactic activity in the presence of POQ, whereas strain AW539 (tar-1) was not stimulated by the presence of this compound.

It has been shown by Galar et al. (5) that several strains of different Rhizobium and Bradyrhizobium species are attracted by POQ. In this study, we have shown that E. coli shows positive chemotaxis toward POQ (Tables 2 and 3). In this chemotaxis, the methylated chemotaxis protein Tar plays an essential role, because a mutant devoid of this protein was no longer attracted by POQ (Fig. 1). The presence of POQ also increased chemotaxis to glucose (Table 3).

The wild-type strain YMC10 showed high GLD and PTS-glucose activities when grown on MM-glycerol (102 nmol of Wurster’s Blue reduced min⁻¹ mg⁻¹ of protein⁻¹ [9] and 40 nmol of sugar phosphorylated min⁻¹ mg⁻¹ [dry weight] [14], respectively). It has been shown previously that simultaneous degradation of glucose via the PTS and GLD in the presence of POQ results in a faster consumption of glucose (8). Adler and Epstein (2) showed that E. coli cells started to swim as soon as the glucose concentration was below 100 mM and that the chemotactic activity was optimal between 1 and 10 mM (our initial glucose concentration was 28 mM). The faster consumption of glucose therefore could be responsible for the increased chemotactic response toward glucose in the presence of POQ. It cannot be ruled out, however, that reoxidation of POOH₂ or reconstitution of GLD by POQ also played a role. The involvement of GLD in chemotaxis to POQ could not be tested because the gcd mutant of E. coli (PPA297) that was available to us was no longer motile. But whatever role the GLD plays in the physiology of organisms such as E. coli, it is of substantial benefit to this organism if it can reconstitute its enzyme to a functional protein by swimming toward POQ.

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