Influence of hydrogen acceptors on growth and energy production of *Proteus mirabilis*

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The generation time of *P. mirabilis* in defined and in complex medium is shorter in the presence of hydrogen acceptors than in their absence. In the presence of hydrogen acceptors the molar growth yield for glucose and the acetate production are strongly increased. From the molar growth yield and the acetate production $Y_{ATP}$ in defined medium was calculated as 5.5 g/mole, whereas in complex medium a value of 12.6 g/mole was obtained. The molar growth yield, the acetate production, the amount of hydrogen acceptor reduced and $Y_{ATP}$ were used to calculate $P/2e^-$-ratios for phosphorylation coupled to electron transfer to oxygen, nitrate and tetrathionate as respectively 2.80; 1.48 and 1.23 in defined medium. Under anaerobic conditions in the presence of nitrate or tetrathionate as hydrogen acceptor in complex medium a bend in the growth curve is observed. In the period of rapid growth the $P/2e^-$-ratio for nitrate reduction is of the same magnitude as that in defined medium, however much lower $P/2e^-$-ratios are found during the subsequent period of slow growth. The $P/2e^-$-ratios for tetrathionate reduction in complex medium for both growth periods are lower than those in defined medium. Most probably these results indicate that during this period growth and energy production are uncoupled. Under aerobic conditions in complex medium a constant $Y_O$ value of 32.2 g/atom O is found during a short period of the growth curve. Afterwards when the cell density increases a steady decrease of $Y_O$ is observed.

**INTRODUCTION**

Bauchop and Elsden (1960) have shown that the growth yield per mole of ATP produced during the fermentation of the energy source ($Y_{ATP}$) is a constant for an organism. In the literature molar growth yields have been reported for a wide variety of substrates with organisms with different metabolic pathways (for
reviews see Forrest, 1969; Stouthamer, 1969; Payne, 1970). Originally the results seemed to indicate that all microorganisms use the energy available from catabolism to produce cellular material with about the same efficiency of conversion. In most organisms about 10 g dry weight of cells are formed per mole of ATP. During the last few years higher values for $Y_{ATP}$ have been reported for a number of organisms (Hobson and Summers, 1967; Buchanan and Pine, 1967; Moustafa and Collins, 1968; de Vries et al., 1970), whereas also a lower value has been found (McGill, 1966). Consequently it does not seem justified to use the mean value of $Y_{ATP}$ calculated from the results of other organisms, for the prediction of the ATP yield for a process in an organism for which $Y_{ATP}$ is not known. However, if $Y_{ATP}$ for an organism is known, this value may be used to predict the ATP yield for processes which are carried out by this organism. This procedure has been used to calculate the ATP production associated with nitrate reduction in *Aerobacter aerogenes*. In this organism $Y_{ATP}$ has been determined (Hadjipetrou et al., 1964). It has been shown that in this organism the molar growth yield for anaerobic growth in minimal medium is strongly increased by the presence of nitrate (Hadjipetrou and Stouthamer, 1965). The total amount of ATP produced, deduced from $Y_{ATP}$, could be used to calculate that about 3 moles ATP were produced per mole of nitrate reduced. Later work has given additional evidence in favour of this value (Stouthamer, 1967).

In *Proteus mirabilis*, oxygen, nitrate, thiosulfate and tetrathionate can be used as ultimate hydrogen acceptors (de Groot and Stouthamer, 1969). The electron transport to these hydrogen acceptors is different as different cytochromes are involved (de Groot and Stouthamer, 1970a, b). Therefore it seemed interesting to study the influence of these hydrogen acceptors on molar growth yields of this organism. The results of this study are presented in this paper.

**MATERIALS AND METHODS**

*Organism.* *Proteus mirabilis* S503 originally obtained from Prof. H. Böhme was used. The properties of this strain have been described before (de Groot and Stouthamer, 1969).

*Media and growth conditions.* Originally the minimal medium described by Böhme (1961) was used. Growth in this medium was very slow however and consequently it was not suitable for the measurement of molar growth yields (de Groot and Stouthamer, 1969). It was found that rapid growth was obtained upon supplementation of this medium with cysteine. The defined medium used subsequently contained per litre water: $K_2HPO_4$, 9 g; $KH_2PO_4$, 1 g; $NH_4Cl$, 5 g; $MgSO_4\cdot7H_2O$, 80 mg; NaCl, 4 mg; $FeSO_4\cdot7H_2O$, 4 mg; $MnSO_4\cdot7H_2O$, 12