Jen Johnson BIOL 310 HW2

Methanogenesis is a metabolic pathway unique to the *Archaea* where hydrogen gas is used to convert a single-carbon molecule into methane. This pathway is bioenergetic, as it produces ATP through the dissipation of a sodium or proton motive force through ATP synthase. However, *Bacteria* do not use this pathway. *Bacteria* do not perform methanogenesis because they would prefer to produce a multipurpose intermediate, retain flexibility in their metabolism, and avoid competition with *Archaea*.

*Bacteria* can use the substrates required for methanogenesis to perform acetogenesis. *Bacteria* prefer this pathway because acetate can be converted into pyruvate, a molecule that is involved with a variety of different metabolic pathways for both anabolism and catabolism. Gray and Tomkins call pyruvate a “keystone molecule” and a “master fuel input.” (1) They found that mutations that cause deficiency in pyruvate-involving pathways cause problems for the organism. One such pathway is fermentation, which *Bacteria* do use. Therefore, acetogenesis is an alternative method of producing pyruvate effectively from a different set of substrates. This redundancy in function suggests that pyruvate is indeed crucial. (2)

The generation of acetate (and the resulting pyruvate) instead of methane and energy is better for *Bacteria* because pyruvate can also be used to generate energy. Acetogenesis produces -105 kJ of free energy per acetate molecule produced via a sodium motive force. On the other hand, the energy yield of methanogenesis is -36 kJ. Therefore, acetogenesis is beneficial for the organism because there is a higher energy yield. Furthermore, the acetate can then be converted to pyruvate by driving the fermentation pathway backwards. When pyruvate enters the citric acid cycle, it produces ATP via substrate level phosphorylation and oxidative phosphorylation. Without quinone enhancement of proton motive force, one molecule of pyruvate yields a total of 30 ATP. The combination of acetogenesis and the citric acid cycle produces more energy than methanogenesis, so this indirect method is favored over the direct production of methane and energy.

In addition to maximizing energy yield, *Bacteria* prefer acetogenesis and pyruvate production because pyruvate can be used as a storage unit. As already mentioned, pyruvate is part of a variety of mechanisms for both energy production and assimilation purposes, so *Bacteria* metabolism relies on pyruvate as a molecule than can be exchanged across different pathways. For example, pyruvate can be used to produce the alanine family of amino acids or glucose via gluconeogenesis. The uses of pyruvate are diverse, and the production of this intermediate gives *Bacteria* flexibility to generate resources as they are needed. This is one reason why *Bacteria* have evolved acetogenesis instead of methanogenesis.

Another reason why natural selection did not favor methanogenesis in the evolution of *Bacteria* is because methanogen metabolisms are not flexible. The direct pathway of methanogenesis is efficient in its energy production, so methanogens evolved to lose alternative and less efficient, pathways to save room in the genome. (3) Therefore, methanogens are strict methanogens, and would not be able to survive by any other metabolic pathway. Furthermore, methanogens are strictly anaerobic. (4) Therefore, their survival requirements are even more narrow. These strict requirements account for one reason why *Bacteria* did not evolve methanogenesis.

Finally, the evolution of methanogenesis in *Bacteria* was not evolutionarily favored because this would increase competition with *Archaea*. The 2 domains already compete for some substrates, but having the exact same pathway would be too much competition. If they had parallel mechanisms and the exact same substrate requirements, they would be competing for the exact same role and niche in the environment. Sulfate reducing and homoacetogenic bacteria already compete with methanogens for hydrogen, so competition for both substrates would not be evolutionarily favored. (4) Under certain conditions, *Bacteria* may be able to outcompete the *Archaea*, but in most cases, the archaealmethanogens would dominate. (5) Therefore, acetogenesis in *Bacteria* evolved to allow for coexistance. If *Bacteria* could not compete with *Archaea*, natural selection would favor another mechanism to them to survive.

Therefore, *Bacteria* do not perform methanogenesis so that they can avoid competition with *Archaea,* produce the crucial and robust intermediate molecule pyruvate, and retain a flexible metabolism.

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I have neither given nor received unauthorized aid on this assignment. Jennifer Johnson