Heterogeneity, signal integration, and synergy in *Bacillus subtilis* spore germination

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Short Abstract —**Spores are formed by some species of gram positive bacteria (e.g., Bacillus) during starvation. They are metabolically dormant and can later germinate into vegetative cells when nutrients (called germinants) reappear. The lag time of germination after encountering germinants is highly heterogeneous for spores in the same population, and the mechanism is still unclear. A quantitative model is developed based on the assumption that the heterogeneity is due to the variability in levels of activated germinant receptors (GR) per spore. The model produces predictions that are consistent with experiments on germination with mixtures of nutrients that trigger different types of GRs, which also suggests that signals from different GRs are summed by a common integrator.**

Keywords **— Spore germination, quantitative model, signal transduction heterogeneity, signal integration.**

I. Introduction

BACILLUS subtilis form dormant spores during starvation, and these spores can later come back to life via germination when germinants reappear [1]. Germinants are detected by a group of germinant receptors (GR) on the inner membrane of spores. Although the decision to germinate is widely studied, has important practical implications, e.g., for food safety, and employs a relatively small set of molecular components, it remains poorly understood. Here we propose a quantitative model, which assumes the level of GRs in a spore is a major factor determining germination.

II. Results

Quantitative Modeling

We show that the model parameters can be fit to give agreement with quantitative measurements of spore germination under a variety of different germination conditions. The model also accounts for the well-known observations that germination of spores from the same population is highly unsynchronized and that some spores are even superdormant (germinate extremely slowly) [2, 3].

Synergy in Spore Germination

Recent experiments show that GRs colocalize in discrete clusters and that different GRs act synergistically in the triggering of germination [4]. This synergy can be advantageous to the survival of the bacteria, as the simultaneous presence of multiple germinants can be a more reliable indication of improvement in the environment than a single germinant.

Modeling Signal Integration

We show here that models for individual GRs can be combined using a simple signal integration mechanism to fit quantitative data for germination induced by germinant mixtures, reproducing the observed synergy between different GR types. This mechanism does not rely on direct interactions between the GRs, which raises the question of why B. subtilis has evolved to co-localize the GRs.

III. Conclusion

In conclusion, bacterial spore germination provides an excellent model system in which to investigate many general features of cell decision processes, including receptor clustering, cell-to-cell variation, and signal combination.

References

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