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PII: S0022-5193(18)30164-4
DOI: 10.1016/j.jtbi.2018.04.004
Reference: YJTBI 9419

To appear in: *Journal of Theoretical Biology*

Received date: 4 September 2017
Revised date: 1 April 2018
Accepted date: 3 April 2018

Please cite this article as: Alexander Tam, J. Edward F. Green, Sanjeeva Balasuriya, Ee Lin Tek, Jennifer M. Gardner, Joanna F. Sundstrom, Vladimir Jiranek, Benjamin J. Binder, Nutrient-limited growth with non-linear cell diffusion as a mechanism for floral pattern formation in yeast biofilms, *Journal of Theoretical Biology* (2018), doi: 10.1016/j.jtbi.2018.04.004

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Nutrient-limited growth with non-linear cell diffusion as a mechanism for floral pattern formation in yeast biofilms

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Abstract

Previous experiments have shown that mature yeast mat biofilms develop a floral morphology, characterised by the formation of petal-like structures. In this work, we investigate the hypothesis that nutrient-limited growth is the mechanism by which these floral patterns form. To do this, we use a combination of experiments and mathematical analysis. In mat formation experiments of the yeast species *Saccharomyces cerevisiae*, we observe that mats expand radially at a roughly constant speed, and eventually undergo a transition from circular to floral morphology. To determine the extent to which nutrient-limited growth can explain these features, we adopt a previously proposed mathematical model for yeast growth. The model consists of a coupled system of reaction-diffusion equations for the yeast cell density and nutrient concentration, with a non-linear, degenerate diffusion term for cell spread. Using geometric singular perturbation theory and numerics, we show that the model admits travelling wave solutions in one dimension, which enables us to infer the diffusion ratio from experimental data. We then use a linear stability analysis to show that two-dimensional planar travelling wave solutions for feasible experimental parameters are linearly unstable to non-planar perturbations. This provides a potential mechanism by which petals can form, and allows us to predict the characteristic petal width. There is good agreement between these predictions, numerical solutions to the model, and experimental data. We therefore conclude that the non-linear cell diffusion mechanism provides a possible explanation for pattern formation in yeast mat biofilms, without the need to invoke other mechanisms such as flow of extracellular fluid, cell adhesion, or changes to cellular shape or behaviour.

Keywords: Saccharomyces cerevisiae, mat formation experiment, angular pair-correlation function, reaction-diffusion, travelling wave solution, geometric singular perturbation theory, linear stability analysis.

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