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Mechanical characterization of individual brewing yeast cells using MEMS: cell rupture force and stiffness

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Abstract

The mechanical properties of individual yeast cells were measured using micro-electro-mechanical systems (MEMS). Samples were taken throughout two controlled fermentations conducted as per ASBC Yeast-14. Two species of yeast: (i) Saccharomyces cerevisiae, "red ale", (ii) Saccharomyces pastorianus, "SMA lager". Individual cells were placed at the MEMS test location and compressed beyond their rupture. Ale cells were found to rupture under an average force of 0.28 ± 0.05 µN across all fermentation phases, while lager cells burst at 0.47 ± 0.10 µN. The average stiffness at the midpoint of fermentation was found to be 4.8 ± 1.0 Nm^{-1} and 5.3 ± 0.9 Nm^{-1} for ale and lager respectively.

Keywords: Brewing yeast cells, Lager, Ale, MEMS, Rupture force, Stiffness, Fermentation, Cell wall.

1. Introduction

The aim of this study was to measure the burst force and stiffness of lager and ale cells at three different fermentation phases (beginning, middle, and end) using an electro thermal MEMS device.

Micro-electro-mechanical systems (MEMS) are devices able to output motions on the order of 1 micron (10^{-6} m). MEMS are used as sensors and actuators in many different applications. In particular, some MEMS have been used as a tool to measure cell mechanics due to their large force range and well defined load conditions[1].

The majority of beer production utilizes lager yeast[2]; however, ale yeast beer has recently become more popular. Lager strains ferment under more adverse environmental conditions than ale and this could lead to a variance in mechanical properties of these species. Furthermore, changes in the cell wall as a response to stress during fermentation[3] could also cause changes on the cell mechanical properties such as rupture force and stiffness.

2. Experimental Methods

2.1 MEMS actuator

A PolyMUMPs (3.5 µm thick movable structure) electro thermal MEMS device was used to compress the cells underwater. Chevron actuators (driven by AC input) push the squeezer downwards and compress the cells against the back spring (see Fig. 1). The jaws have a multi-step design allowing cell diameter to be in the range of 4.5 to 8.5 µm (see Fig. 2). Knowing the stiffness of the back spring (k_{bs}) and the displacements of the squeezer (Δ_{in}) and the back spring (Δ_{out}), the stiffness of the cell (k_{cell}) can be calculated by:

$$k_{cell} = \frac{k_{bs} \cdot \Delta_{out}}{\Delta_{in} - \Delta_{out}}$$

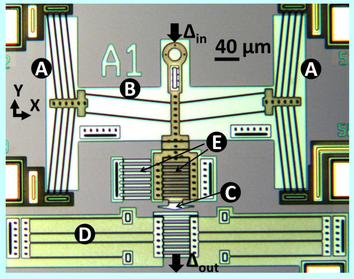

Fig. 1: MEMS squeezer device. Chevron actuators (A), V-shaped amplifier (B), jaws (C), back spring (D), and optical combs (E).

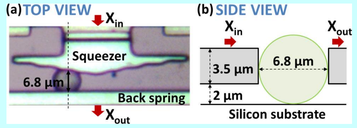

Fig. 2: (a) Microphotograph of a cell placed in between the jaws. (b) Illustration of the cross section of the microphotograph.

2.2 Yeast growing

The two species of yeast (Table 1) were taken from two miniature fermentations (Fig. 3) conducted as per YEAST-14.

Table 1: Yeast assessed in this study

Species	Strain	Source
Ale *S. cerevisiae*	Nottingham ale	Lallemand
Lager *S. Pastorianus*	SMA	Wyeast

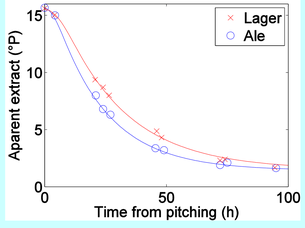

Fig. 3: Attenuation of extract over the fermentation.

2.3 Testing Procedure

The cell was captured by micropipette aspiration and brought to the test location. The input voltage was incremented from 0 to 12 V_{RMS}. Microphotographs of the test location were taken after each voltage change and sequence of images showing the cell compression was recorded. Displacement measurements were done by a FFT image analysis algorithm with a precision of ~ 10 nm.

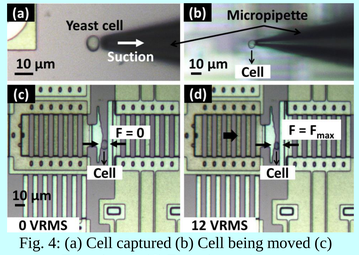

Fig. 4: (a) Cell captured (b) Cell being moved (c) Force is null (d) Force is maximum.

3. Results and Discussion

3.1 Burst force

One cell: in this example the cell experienced a growing force from 0 to 1.01 µN. When the force reached 0.45 µN the cell cracked (Fig. 5). The plot of force vs cell deformation (Fig. 6) shows a discontinuity of ~0.5 µm and a drop on the slope (stiffness) after burst .

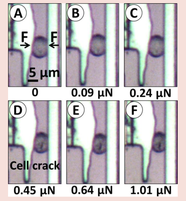

Fig. 5: Force increases from A to F. Burst occurs at D.

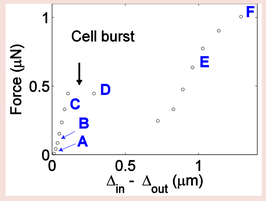

Fig. 6: Force vs. deformation data of the tested cell .

All cells: 32 cells (15 lager, 17 ale) were tested. The average lager burst force was 0.47 ± 0.10 µN while ale was 0.28 ± 0.05 µN across all fermentation phases. The fermentation phase did not significantly change the burst force. Figure 7 shows the average rupture force for each species at each fermentation phase. At least 5 tested cells for each point in the graph and error bars show standard deviation.

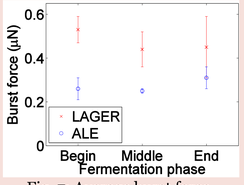

Fig. 7: Average burst force.

3.2 Pre and post-rupture stiffness

Average lager pre-rupture stiffness was 5.3 ± 0.9 Nm^{-1} while ale was 4.8 ± 1.0 Nm^{-1}. Therefore, no significant difference between species was observed. Pre-rupture stiffness was ~5 times the post- rupture for both species. Figure 8 shows the average pre and post-rupture stiffness for ale and lager mid-fermentation yeast cells (total of 20 cells), error bars show standard deviation.

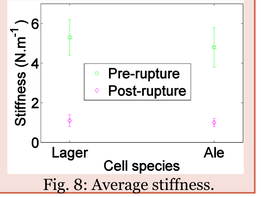

Fig. 8: Average stiffness.

4. Conclusions

Lager cells burst force was ~2x greater than ale cells burst force. Nevertheless, no significant difference in stiffness was observed. Burst force and stiffness did not change significantly over the different fermentation phases for each species.

References

[1] O. Loh, A. Vaziri and H. Espinosa. The potential of MEMS for advancing experiments and modeling in cell mechanics. Exp. Mech. 49(1), pp. 105-124. 2009. . DOI: 10.1007/s11340-007-9099-8
[2] Canadean. "Beer, Cider and Flavored Alcoholic Beverages Market," 2011
[3] B. R. Gibson, S. J. Lawrence, J. P. R. Leclaire, C. D. Powell and K. A. Smart. Yeast responses to stresses associated with industrial brewery handling. FEMS Microbiol. Rev. 31(5), pp. 535-569. 2007. DOI: 10.1111/j.1574-6976.2007.00076.x