Approximating Yeast Nutrient Timing for Making Wine in my Closet

Reese Kilbarger-Stumpff

CSCI 3656 – Numerical Computation

Dr. Osita Onyejekwe

Abstract:

When making wine, yeast produce the best product in an environment where they have adequate nutrients. Juice itself does not contain this, so it is recommended to add yeast nutrient at ⅓ and ⅔ sugar depletion. My goal was to get a time approximation for these sugar depletion percentages, called sugar breaks, at the specific temperature (72°F) and yeast type I typically use. I took measurements of the sugar percentage, called specific gravity, over the course of 10 days, getting points indicating the rate of fermentation. With these data, I approximated continuous functions using Cubic Splines interpolation, and I used a modified Newton's root-finding method to obtain a time value for those sugar breaks. I found that for a bottle started with cold yeast, the sugar breaks come at ~23.6 hours and ~69.8 hours after pitching, and the bottle started with warm yeast had sugar breaks ~18.4 and ~46.4 hours after pitching.

Background:

Wine is made primarily by mixing yeast with fruit juice. The yeast, once they have established a colony, will metabolize the sugar in the juice, producing alcohol as a by-product. However, yeast, much like humans, will not be very healthy when supplied with just sugar as food, and they will produce often undesirable flavors in the wine if this is the case. Thus, it is advised[1] to some kind of yeast nutrient, containing things like nitrogen and phosphorus, into a fermenting wine at some stage. While there is debate around when to add these nutrients, one prevailing scheme is to stagger the nutrient additions across the fermentation so as not to overwhelm the yeast. I am choosing to investigate adding nutrients when there is ⅔, and then ⅓ of the original sugar present in the mixture, called sugar breaks. I am doing this primarily because this is the most detailed schedule I will actually apply going forward, and I hope to use these results for myself.

The process of assessing a fermentation midway involves measuring the percentage of sugar in the liquid in a unit called specific gravity. With my equipment (detailed below), the process is generally invasive and has the potential to introduce contaminants in the form of other fungi and bacteria, which means that ideally, one measures a fermentation as little as possible. Therefore, my goal is to get an approximation for where the ⅓ and ⅔ sugar breaks are in terms of hours since the yeast was added. This is very dependent on the fermentation temperature and type of yeast used, so these results are really only relevant for a 72°F environment using bread yeast.

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[1] Most of the research in this area is proprietary, done by the wine industry, and thus inaccessible. Also, much like cooking, it is difficult to define "undesirable flavors", so research is limited in terms of what makes for the "best" fermentation. As such, these assertions come from a mix of folk knowledge in the community and personal experience. Here, I'm picking a process and using the math to do it precisely. The specific chemistry and other approaches don't matter too much to me.

Experimental Setup and Data Collection:

The plan initially was to take a gravity measurement every 4 hours for 10 days, which for me is not feasible. Then, I planned to approximate this by making two identical wines, but starting them 4 hours apart, so I could measure them every 8 hours, merge the data, and end up with a continuous-seeming dataset. However, I learned quickly that slightly different conditions in the bottles make this impossible, so I ended up with two vastly different ferments, measured every 8 hours for 10 days.

Materials:

- 2x half-gallon Tree Top apple juice
- White sugar (until 1.1 gravity)
- 10g Fermaid-K yeast nutrient (5g per bottle)
- ½ cup yeast slurry (¼ cup per bottle)

I mixed the two bottles of apple juice together in one container, and added sugar until the specific gravity was 1.100. The yeast came from the same colony, initially a bread yeast that I saved from making a lower gravity cider. This was so I knew these yeast were capable of surviving in alcoholic environments and wouldn't be too stressed already. They were stored at 40°F until pitching, so I mixed them with some warm water to bring them out of dormancy. I put half the apple juice in one of the ½ gal. bottles, along with 5g of yeast nutrient to get things started. Then I put the yeast in, shook it up to mix, and stabbed some air holes in the cap. Four hours later, I repeated the process with the second bottle. However, I neglected to take into account that the yeast had warmed and begun blooming in the room temperature water over those four hours, speeding fermentation onset in the second bottle.

Figure 1: Hydrometer in test cylinder measuring gravity of water (1.000)

Taking a Gravity Measurement:

- Turkey baster
- Test cylinder
- Hydrometer
- Sanitizer

Sanitize the hydrometer, baster, and test cylinder with iodine solution. Once dry, use the turkey baster to move enough of the wine to the test cylinder that the hydrometer will float. Once the hydrometer is stable, record the reading from the hydrometer and pour wine back into the container.

This constant mixing and contact with outside air and surfaces, however sanitized they may be, can introduce contaminants that can ruin a wine as it ages. As such, I'd like to limit doing that on good batches of wine later on, so I'll take tons of measurements on a low-effort batch here.

Numerical Computation Methods:

Once I had the data in a CSV, my goal was to approximate the function governing the fermentation rate with some kind of interpolating polynomial, and then use that polynomial to understand when the sugar breaks happened.

Cubic Splines:

Of the interpolating methods, cubic splines interpolation works the best. Linear interpolation, while straightforward, wouldn't capture the curves in the way I wanted, and a lagrange polynomial was unstable enough approximating an exponential decay function that it wasn't worth it[2]. The lagrange method would be using a polynomial of degree 30, which lends itself to instability. Also, the cubic spline's derivative is easily obtainable, which makes it a natural fit for many root-finding methods.

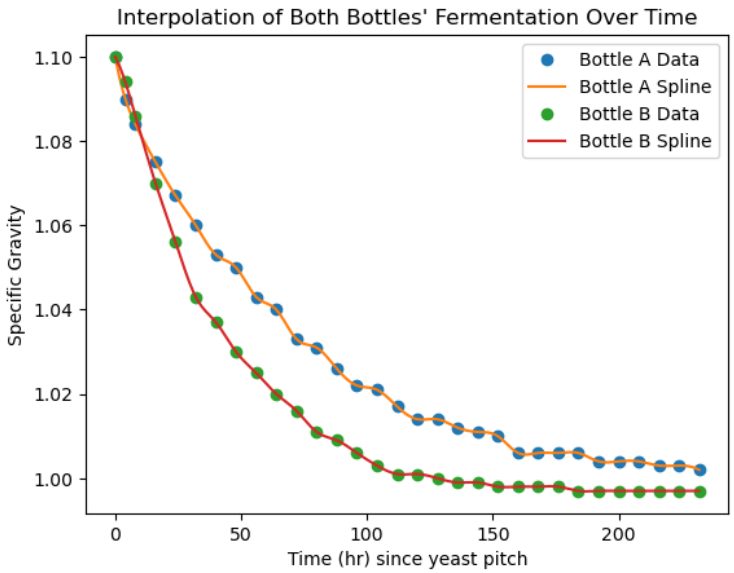

Figure 2: Plot displaying the collected S.G vs time data, along with interpolating splines for both bottles. Bottle A was the cold yeast start and Bottle B was the warm start

As evidenced by Fig. 2, the bottle pitched with warm yeast fermented much quicker, and as such had a more complete fermentation at the end of the 10 days. Also, the data are so discretized because of how few points there are that the interpolating polynomial is very wavy, almost like a step function at points. This is partially due to the lack of precision in my

[2] Honestly the best tool here would have been an exponential fit, but this isn't a stats class, so here we are.

measuring setup, but the polynomials still approximate the exponential decay curve of sugar percentage.

Newton's Method

To find the time at which the sugar breaks occurred, I decided to use a root-finding method on my cubic spline. Newton's method was the natural fit here: it is precise in few iterations, and the derivative of the cubic spline is easily available. To make the root-finding applicable, I calculated ⅓ of the fermentable sugars: $\frac{\text{grav}_{\text{final}}\text{-grav}_{\text{initial}}}{3}$ and added and subtracted it to the final and initial gravities respectively. From this, I constructed splines with the data shifted down by these amounts.

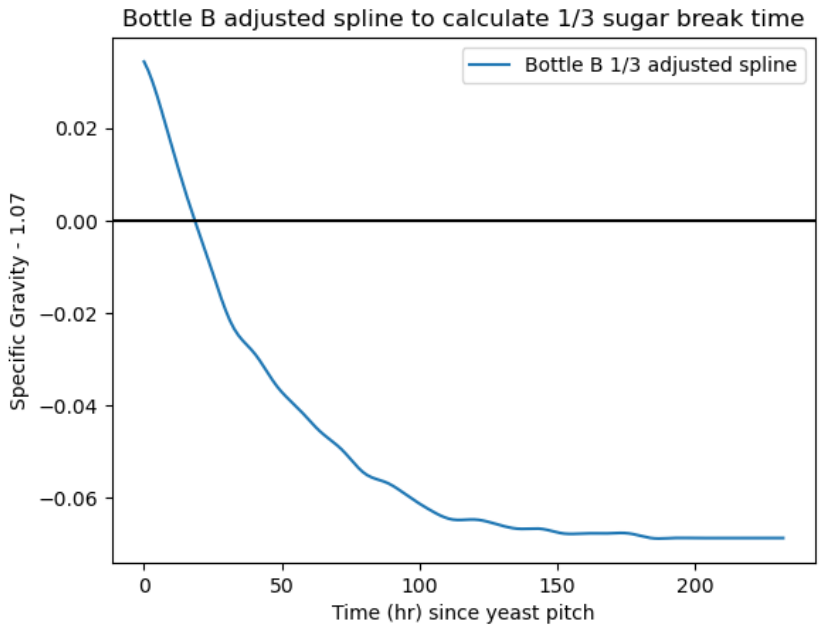

Figure 3: Plot of the adjusted spline indicating Bottle B's 1/3 sugar break. This was what newton's method evaluated

Once the I had all 4 shifted splines constructed, I applied our in-class newton's root-finding method code, obtaining the time for each of these sugar breaks, and was able to plot them alongside the splines.

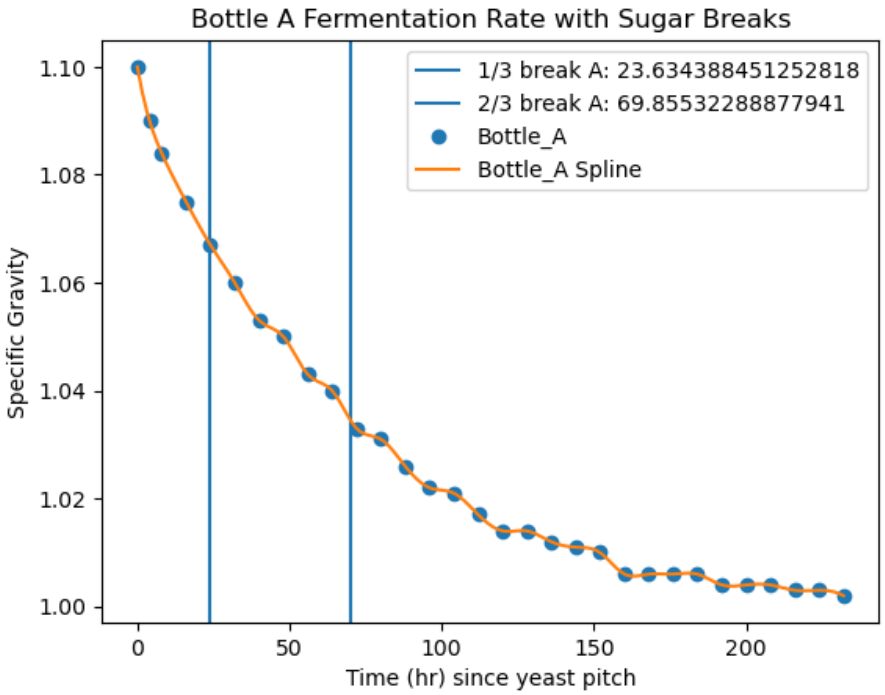

Figure 4: Bottle A's spline and data, along with the calculated sugar break times plotted alongside them.

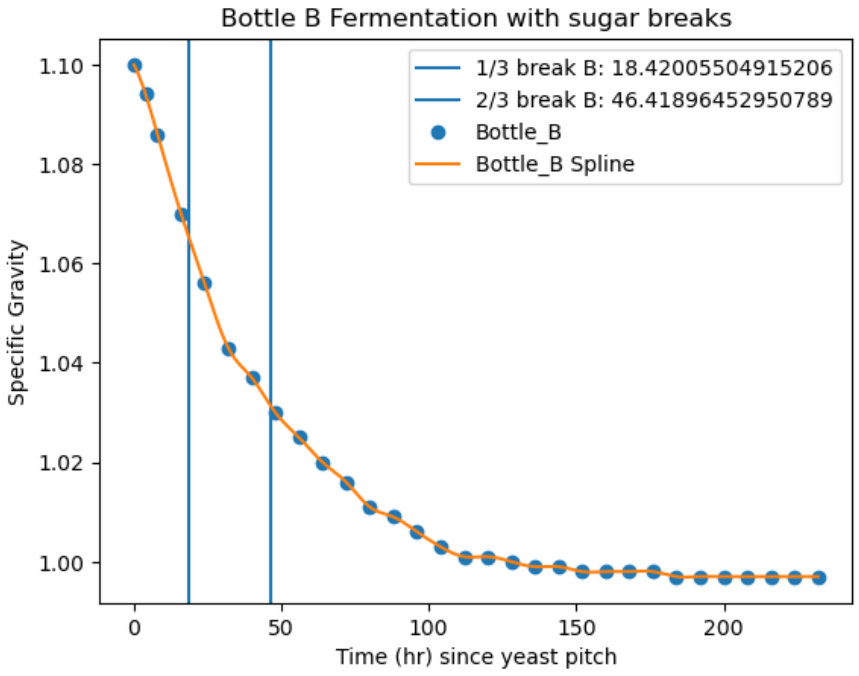

Figure 5: Bottle B's spline and data, along with the calculated sugar break times plotted alongside them

Conclusion:

With cold yeast, the sugar breaks come at 23.6 hr and 69.8 hr approximately. With warm starting yeast, the sugar breaks come at 18.4 and 46.4 hr. The precision here might be misleading, however. In getting this result, we have two approximations stacked on top of each other (Newton's finding a root of the visibly wonky cubic splines). The way I'm going to interpret this result is if I start with ~40°F yeast, I should add nutrients exactly 1 and 3 days after pitching, and if the yeast is room temp and blooming in water, I should add nutrients about 18 hours and 2 days after pitching.

Upon reflection, this was a good procedure to solve this problem. I wanted an approximation to sugar breaks in the environment of my fermentation closet, and now I have a much more precise ballpark than I did before (used to think ⅔ sugar break was ~4-5 days), and I'll probably use the results to make a mead very soon.

Github Link: https://github.com/reesekshub/numCompFinal

YouTube presentation: https://youtu.be/pqjKgsEFvlg