Yeast Growth

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- Abstract

How does the population of yeast cells grow? Is it much different to use an unrestricted growth model or a logistic equation model to explain this growth? To test this, our goal was to examine yeast population growth under ideal conditions but in a confined space, using these two different models. We compared the shape of their growth graph and also estimated the time consumed for a yeast cell to reach its maximum population. The result demonstrates the necessity of incorporating the environmental limitations and resource competition factors into the model to illustrate the growth of Yeast.

- Introduction

"The yeast species Saccharomyces cerevisiae is a budding yeast that is used extensively around the world in baking and brewing, and is one of the best studied model organisms. As a budding yeast, cell division is assymetric, with smaller daughter cells grow out from the surface of a mature parent cell, ultimately separating into a distinct individual. Under optimal growth conditions, it can have a doubling time as fast as 90 minutes."(Green 192p) A good approach to understanding the growth patterns of yeast populations is to create mathematical models and examine graphs. Based on this information, we assume that when our model is under ideal conditions, the population of yeast may double every 90 minutes. However, in real-world conditions, factors such as limited space and competition for resources affect the growth rate of the population. To test the differences between the growth of a yeast population under unrestricted growth conditions and limited conditions imposed by environmental factors, we used two different models containing each condition. As a continuously growing species, the growth of yeast can be modeled either by an unrestricted (exponential) growth model or by the logistic equation model.

An unrestricted(exponential growth model):

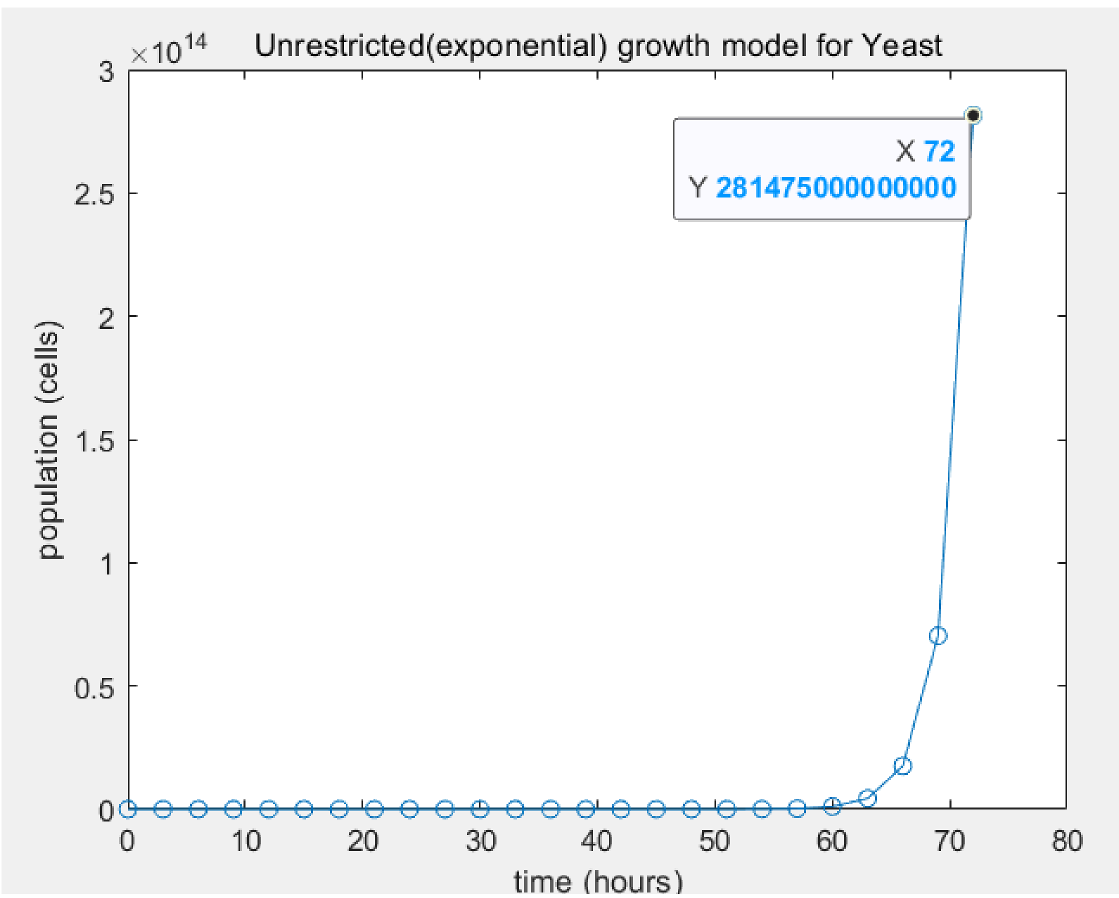
$$\frac{dN}{dt} = R_o N(t) \rightarrow N(t) = N_0 e^{R_o t} = N_o 2^{\left(\frac{t}{\tau_2}\right)}$$

A logistic equation model:

$$\frac{dN}{dt} = R_o N(t)\left(1 - \frac{N(t)}{K}\right) \rightarrow N(t) = \frac{K N_0 e^{R_o t}}{K - N_0 + N_0 e^{R_o t}}$$

- Results and Discussion

We first began with a single yeast cell and assumed that it grew under ideal conditions for three days. For this experiment, we used an unrestricted growth model and plotted the number of cells expected to be present every 3 hours.



Through the above graph, we can see the shape of the growth of yeast cells under ideal conditions without any restriction. And we got 2.8147e+14 (the number of cells) cells at the end of the three days. Also when we think about the shape of the yeast cells, since they are approximately spherical, we can calculate the volume of a yeast cell and the volume in liters that they would occupy after 3 days. Since their typical diameter is 6 μm, we can get the volume of a yeast cell in liters, which is 1.1310e-13(m^3), and after 3 days they become `L*sim(k)=` 31.8341(L).

Now, we want to check how long it takes for yeast cells to fill out a given area without considering any condition. let's consider an experiment biologist growing a culture of yeast cells. She begins with a small number of yeast cells (we set it as 10,000) selected from an agar plate and transfers them to a 2 L flask containing 1 L of liquid growth medium.

```
% main parameters
N0 = 10000; % Beginning with a single yeast cell
timev = 0:1:24*5; % time vector for every one hours
tau2 =  1.5; % doubling time of yeast is 1.5hours
N = N0; % N is a number; N0 is a initial value
r = 3/(1e+6); % radius of Yeast (m)
vol = 4/3*pi*r^3; % volume of a Yeast(m^3)
L = vol*10^(3); % liter of a Yeast(L)
% Simulation
k=0; % counter
max_t=0; % hours to fill 1L
for t=timev
   k=k+1;
   % main equation
   N = N0*2^(t/tau2);
   % find out how many hours it takes to fill 1L
   if L*N>=1 max_t=t;break; end
end
```

As a result of these codes, we got the max_t = 45(hours) which means she needs to wait 45 hours to reach the maximal number of yeast cells possible in her system.

However, the above growth model neglected the competition of yeast cells for resources due to the limited environmental capacity. For yeast, the maximal density achievable in liquid culture is about 2*10^8 cells per mL. So, we could get a carrying capacity for a 1L total volume.

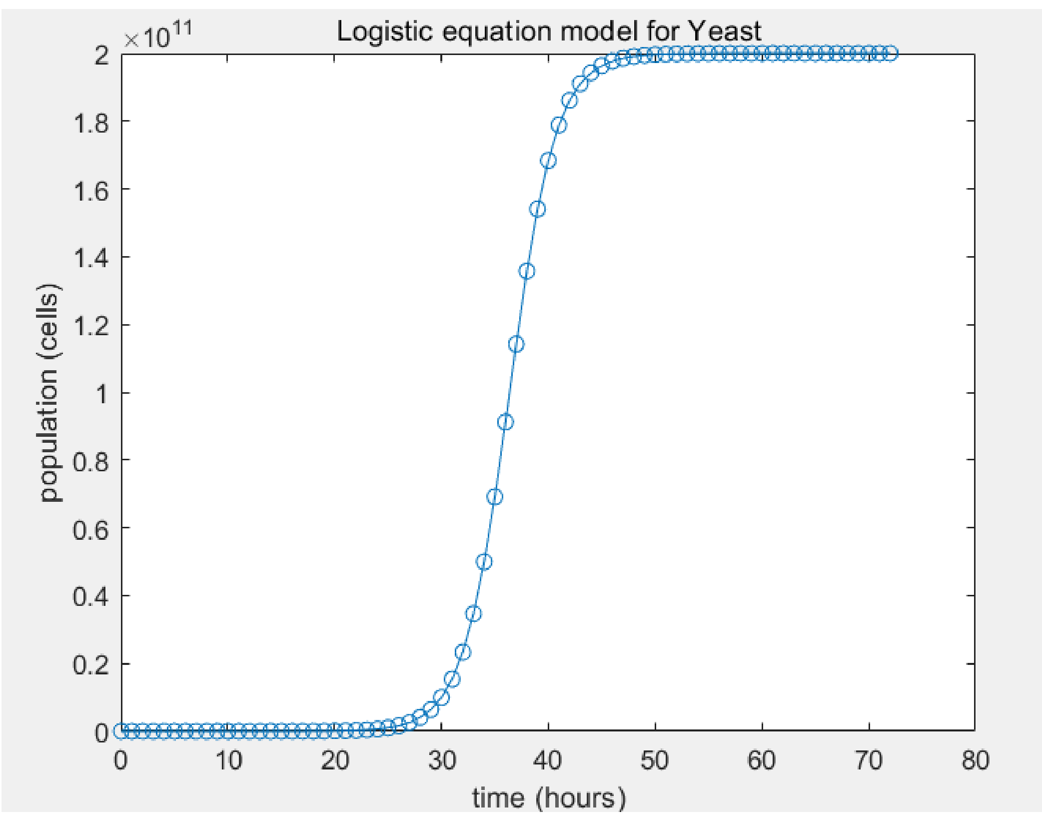
```
max_d1 = 2*10^8; % maximal density of yeast cells per mL
max_d2 = max_d1*1000; % maximal density of yeast cells per L
r = 3/(1e+6); % radius of Yeast (m)
vol = 4/3*pi*r^3; % volume of a Yeast(m^3)
L = vol*10^(3); % liter of a Yeast(L)
L*max_d2
```

Through these codes, we got a carrying capacity 2.0000e+11(cells) for a 1L total volume. We could get a total volume that could be occupied by the maximum number of yeast cells in 1L, which is max_d2*L= 0.0226 (L) or max_d2*vol= 2.2619e-05 (m^3).

Finally, with this carrying capacity, we can use the logistic growth model considering the competition for resources and the impact of limited environmental capacity. We used this logistic growth model in the same situation(same initial values) above to check how long it takes to reach a maximal number of yeast cells inside the 2 L flask containing 1 L of liquid growth medium.

```
%%%%%%%%%%%%%%%%%%%%
%% Logistic equation(Q 5)
%%%%%%%%%%%%%%%%%%%%
% main parameters
N0 = 10000; % Beginning with a single yeast cell
timev = 0:1:24*3; % time vector for every one hours
tau2 =  1.5; % doubling time of yeast is 1.5hours
N = N0; % N is a number; N0 is a initial value
r = 3/(1e+6); % radius of Yeast (m)
vol = 4/3*pi*r^3; % volume of a Yeast(m^3)
L = vol*10^(3); % liter of a Yeast(L)
K= 2*10^8*1000; % carrying capacity for 1L
% Simulation
```

```
sim = zeros(length(timev),1); % vector to store the values of N during
simulation
i=0; % counter
max_t=0; % hours to fill 1L
for t=timev
   i=i+1;
   % main equation
   N = (K*N0*2^(t/tau2))/(K-N0+N0*2^(t/tau2));
   % find out how many hours it takes to fill 1L
   if max_t==0 if N>=K max_t=t; end; end
   % store value of N for plotting
   sim(i)=N;
end
% plot
figure(2); clf
plot(timev,sim,'-o')
xlabel('time (hours)');ylabel('population (cells)')
title('Logistic equation model for Yeast')
```



The graph above shows that the number of yeast cells keeps approaching the carrying capacity and we can say that after 48 hours it roughly reaches the carrying capacity. This means the biologist needs to wait 48 hours to roughly see the number of yeast cells possible in her system in real-world conditions.
Even though there is not much time difference in reaching each maximal population inside 1L between the unrestricted growth model and the logistic growth model, the numbers of cells that each model reached at that time are very different. Since the unrestricted growth did not consider the maximal density that yeast cells can achieve and just calculated the time to fill out 1L, we can not use this model in the real-world situation.

- Conclusion

In this study, we made computational models for the population growth of yeast using both the unrestricted growth model and the logistic growth model. The unrestricted model showed exponential growth in yeast cells and even one of the experiments showed that it could reach 32 liters of volume after three days. However, the logistic model considering the environmental limitations, demonstrated a more realistic growth in which the population stabilized around the carrying capacity because of the competition for resources. Even though both of the models suggested that yeast cells could reach the maximal number of cells in a given space within a similar time, the numbers of cells that each model reached at that time were very different. This highlights the importance of considering biological conditions such as resource limitations in population growth models.
In conclusion, the logistic growth model provides a more accurate simulation of yeast growth for real-world conditions, emphasizing the importance of considering environmental limitations in mathematical models.

- References

David Green (2024). *Yeast Growth*

I have only used the information inside the homework paper