SENIOR CAPSTONE/ SENIOR DESIGN EXPERIENCE 2025

Probiotic Boba Milk Tea

Zeno Ruttens[1], Eli Cade[1], Adam Francis[1]

[1]Biological and Food Process Engineering, Purdue University

PURDUE UNIVERSITY

Agricultural and Biological Engineering

Objective

The objective of this project was to create a gut-healthy probiotic boba milk tea as with an innovative delivery system. The goal is to sell a product that provides natural energy and stress relief.

Background

Target Consumer
Health-conscience adults, like college students.

Market
Probiotic drinks market was valued at $39.74 billion in 2023, with projections indicating growth to $98 billion by 2033 (Spherical Insights & Consulting, 2024).

Competitors
Yakult, GT's Kombucha, Bio-K+ and other drinks centered around probiotics.

Ethical & Societal Implications

- Ethically source raw materials to align with consumer expectations
  - Alginate, mango concentrate, etc.
- Rapid adoption of probiotic drinks in North American and Asia Pacific
- Exhibits improved digestive health access through an enjoyable format
- Proper waste management
  - Water recycling, chemical waste

Nutrition Label

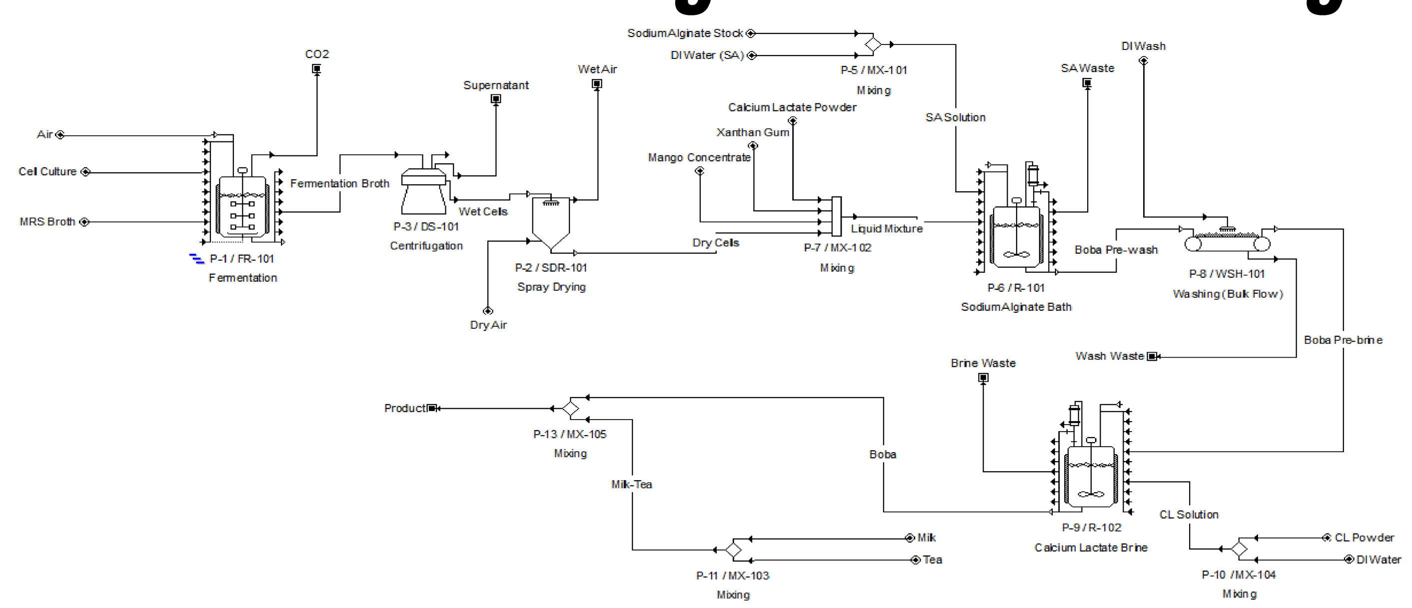
Nutrition Facts Servings: 1, **Serv. Size: 1 can (454g),** Amount Per Serving: **Calories 130, Total Fat** 0g (0% DV), Sat. Fat 0g (0% DV), *Trans* Fat 0g, **Cholest.** <5mg (1% DV), **Sodium** 80mg (3% DV), **Total Carb.** 29g (11% DV), Fiber 0g (0% DV), Total Sugars 28g (Incl. 20g Added Sugars, 40% DV), **Protein** 5g, Vit. D (8% DV), Calcium (25% DV), Iron (0% DV), Potas. (6% DV).

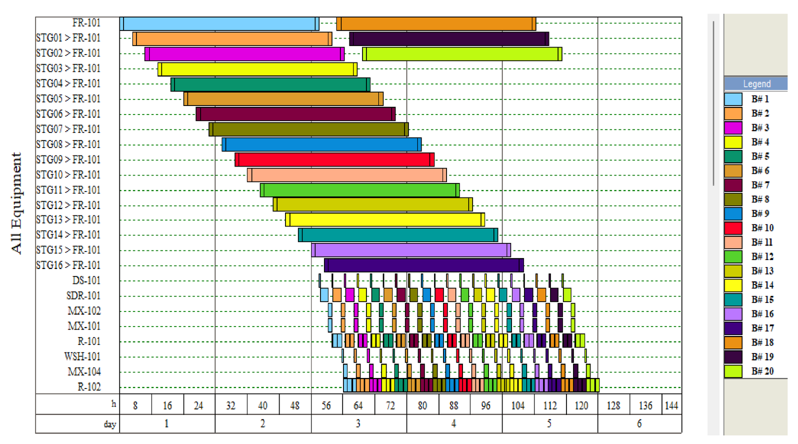
INGREDIENTS: BLACK TEA (WATER, BLACK TEA), SKIM MILK (FAT FREE MILK, CALCIUM LACTATE), SUGAR, MANGO NECTAR, CANNED, CALCIUM LACTATE, XANTHAN GUM

CONTAINS: MILK

Each serving contains 10 billion CFU of *Lactobacillus Plantarum*

Process Flow Diagram & Scheduling



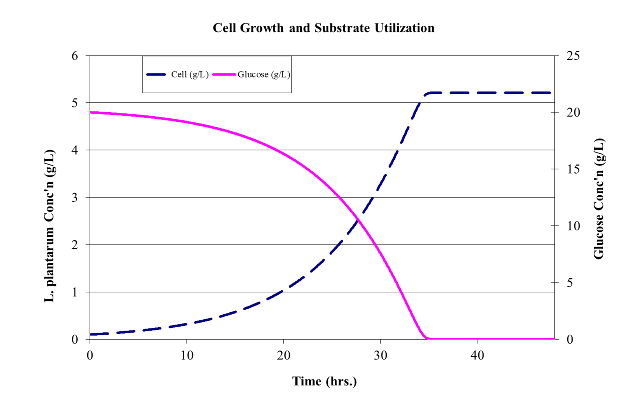


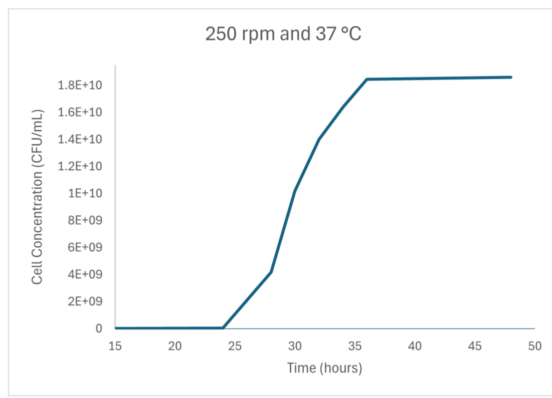
Process Controls & Alternatives

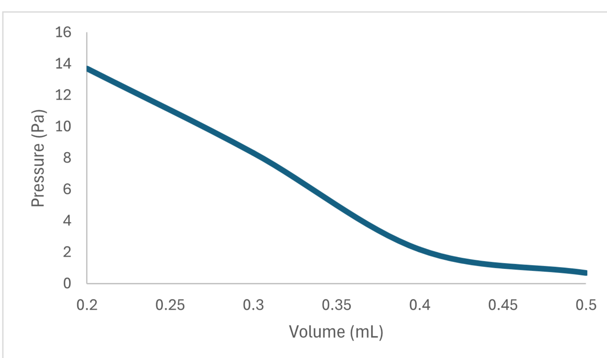
Process	Controls	Alternatives	Benefits
Fermentation	RTD sensor; positive feedback loop to control temperature of water in the jacketed vessel	**Jacketed aerobic fermentation**, anaerobic batch fermentation, continuous fermentation	Produces highest yield of *Lactobacillus Plantarum* when agitated
Drying	Humidity sensor to control inlet temperature	**Spray Drying**, Freeze Drying, Vacuum Drying	Cost effective, faster process, and consistent moisture content
Encapsulation	Flow sensor to ensure consistent droplet formation	**Reverse Spherification**, Basic Spherification, Extrusion Encapsulation	Formation of stronger beads and longer shelf life

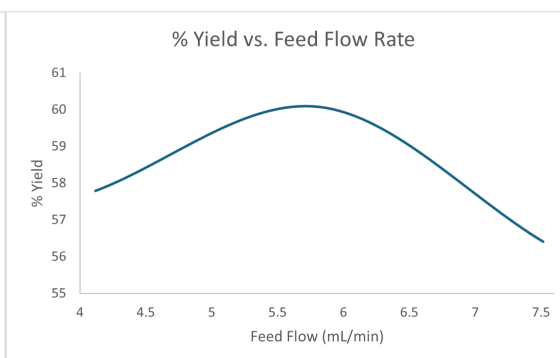
Experimental Design

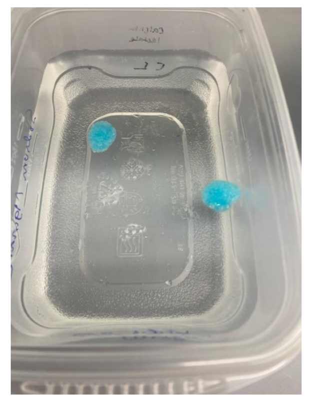
- **Aerobic Fermentation:** Inoculated MRS Broth with one tablet of starter culture. Agitated in the incubator at varying agitation speeds and temperatures. Measured cell concentration over time using spectrophotometer at 600 nm
- **Spray Drying:** Drying a mixture of cells and water to separate cells as dry mass via atomization with air. Feed flow rate, air flow rate, and process time were varied to obtain optimal conditions
- **Bioencapsulation:** Encapsulation of probiotics via reverse spherification using calcium lactate and sodium alginate. Concentration of calcium lactate in the liquid solution and residence time in the brines were tested to obtain proper bead rigidity





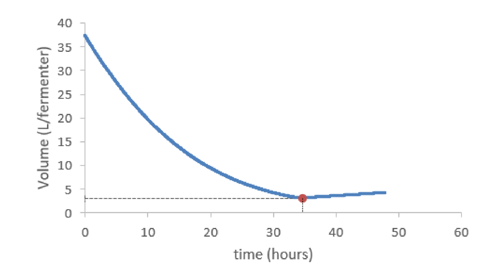






Optimization

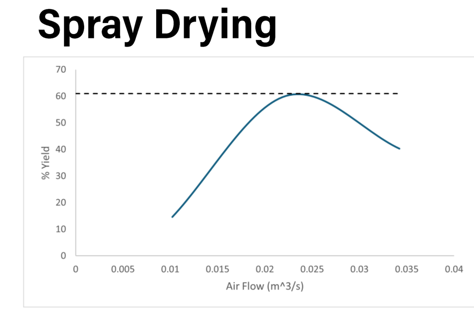
Fermentation



$$\frac{dX}{dt} = \mu X = \frac{\mu_{max} S}{K_S + S} X \qquad Y_{xs} = \frac{X - X_o}{S_o - S} \qquad \frac{dS}{dt} = -Y_{SX} \cdot \frac{dX}{dt}$$

- Variable chosen was batch time in the fermenter
- Directly related to volume
- Optimum batch time was 34.7 hours, optimum volume was 2.99 L per fermenter

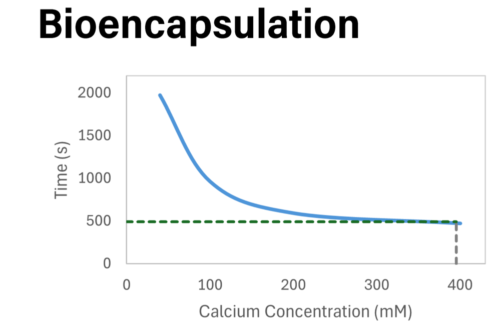
Spray Drying



$$L_s(X_0 - X_f) = G(H_2 - H_1) \qquad \dot{V}_{out} = v * A_{vent} \qquad Y_{dry} = \frac{m_{dry,collected}}{m_{wet,input}}$$

- Variable chosen was air flow rate through the spray dryer to reach maximum yield
- Maximum percent yield was 61% at an air flow rate of 0.0222 m^3/hr
- Moisture content and cell viability also impacted by air flow rate

Bioencapsulation

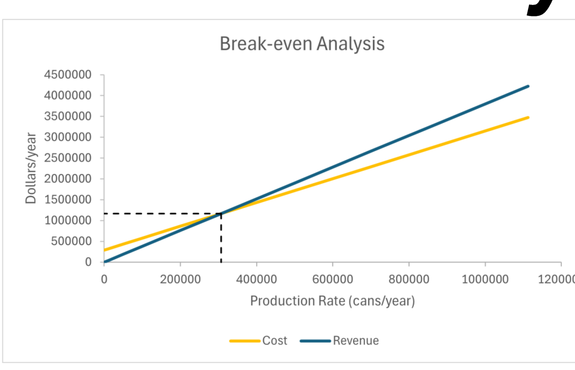


$$\frac{da}{dt} = D_a \frac{d^2 a}{dx^2} - \frac{dg}{dt} \qquad \frac{dc}{dt} = D_c \frac{d^2 c}{dx^2} - N_c \frac{dg}{dt}$$

$$\frac{dg}{dt} = ka(a+g)c = k' ac$$

- Variable chosen was calcium concentration in the liquid mixture, optimized value was 86.3 g/L to reach the desired shell thickness
- Optimized concentration minimized raw material cost of calcium lactate and cost of the sodium alginate reactor

Economic Analysis



- Using a selling price of $3.80/can
- Break-even production rate occurred at 307,285 cans/year
- 27.63% plant capacity required to surpass break-even production rate

Initial & Yearly Costs	
Total Capital Investment ($)	678,485.00
Raw Material Cost ($/year)	692,943.83
Purchased Equipment Cost ($)	134,745.85
Capacity Production Rate (cans/year)	1,112,100
Cost Per Can ($/year)	2.86
Selling Price ($/can)	3.80
10-Year Outlook	
Net Present Worth ($)	1,524,639.80
DCFR (%)	38.50
Recovery	20488.78

Recommendations & Future Work

Fermentation	Spray Drying	Bioencapsulation
For future work we recommend the addition of other growth factors to increase cell yield and decrease batch time and volume requirement of equipment	To increase viability of the cells, we recommend using a protectant with the spray like maltodextrin or whey protein	For future work we recommend using a different method of encapsulation to increase product yield.

Instructor: Dr. Martin Okos
Advisor: Daniel Hauersperger

Acknowledgements to the Agricultural and Biological Engineering Department and Faculty, Purdue University. Special thanks to Mandy Limiac and Daniel Hauersperger