SENIOR CAPSTONE/ SENIOR DESIGN EXPERIENCE

2024

Probiotic Digestive/Skin Health Powder

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PURDUE UNIVERSITY

Agricultural and Biological Engineering

Objective

This product aims to provide novel consumer benefit through a powdered drink mix that provides probiotic benefit by containing live bacteria to improve digestive and skin health for consumers. With a convenient powdered form, this product is accessible to consumers while reducing environmental impacts of using and shipping large quantities of water. The process of developing this product from an engineering perspective is explored through this capstone project.

Market Analysis

$21 billion USD market for skin & digestive health products

- Global Beauty Market $2.78 billion/year
- Global Digestive Health Market $10.51 billion/year

57% of Americans take daily supplements

- 36% take supplements for hair, skin, & nails
- 41.71% take probiotic supplements

60 million consumers in total addressable market

↓

6 million consumers assuming 10% of total market

↓

~26 billion servings produced annually

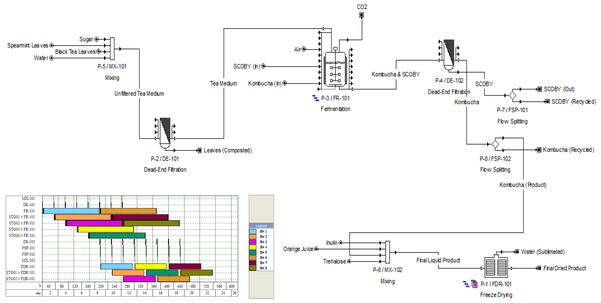
Industry Trends

- Increased focus on gut and skin health
  - gut-skin axis
  - "health from within"
- Demand for healthy & convenient beverages

Ethical Considerations

- Zero waste & low carbon emissions
- Sustainable sourcing
- Transparent labeling -> live probiotics

Process Operations & Scheduling



***Sterilization*:**

- High Heat Short Time Treatment (HTST)
- Treatment Parameters: 72 °C for 5.4 seconds
- Target: 9-log kill of *C. burnetii*

***Mixing*:**

- 1st mixing step: water, spearmint, black tea, sugar
- 2nd mixing step: fermented liquid, inulin, orange juice, and trehalose
- Final liquid product is 1000 kg before freeze drying
- 21 kg of spearmint and tea leaves are filtered after first mixing step

Fermentation

- 7-day fermentation operated at room temperature
- Bacterial inputs: SCOBY & kombucha, sucrose substrate
- Final liquid product is 1.62% bacteria & yeast by mass
- SCOBY & starter kombucha are recycled for future batches

Freeze Drying

- Input: fermentation product mixed with cryoprotectant
- Batch is frozen at -20°C and dried at 80°C for ~30 hours
- Target final moisture content is 2%

Zero Waste Optimization

- Carbon footprint is reduced by 90.8% using renewable energy
- Tea and spearmint leaves are composted after filtration
- Operating fermentation at room temperature, selling excess SCOBY to home brewers
- Filter excess water before freeze drying and recycle sublimated water into mixing

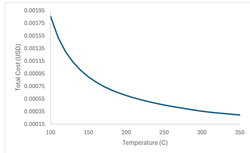
Unit Operation Alternatives

- Pasteurization or ultra high temperature (UHT)
- Inline mixing, turbine agitation
- Designing continuous kombucha fermentation
- Convective hot air drying or spray drying

Optimization & Modeling

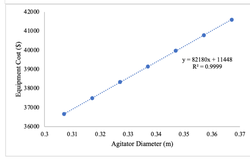
Sterilization

- Increased steam temperature reduces cost. Setting steam to 300℃ was found to be the most optimal



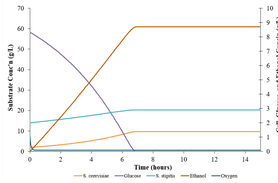
Mixing

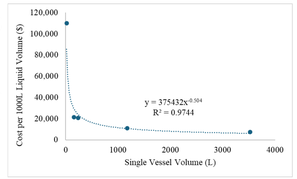
- Smaller agitator diameter reduces cost, 0.307 m propeller agitator is optimal



Fermentation

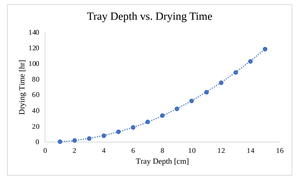
- Larger vessels reduce cost, 1,100 L tanks are optimal





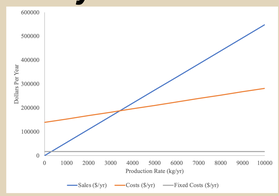
Freeze Drying

- Shallow tray depth decreases drying time, 12.3 cm is optimal



Business & Economic Analysis

The breakeven point for this product occurs at a production rate of 3249.12 kg/year or 44.1% plant capacity



	Year 2 - Quarters				Year 3 - Quarters			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Profits:								
Annual Sales	$ 86,347.19	$ 86,347.19	$ 86,347.19	$ 86,347.19	$ 109,268.45	$ 109,268.45	$ 109,268.45	$ 109,268.45
Losses:								
Total direct plant costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total indirect plant costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fixed Capital Investment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Working Capital Investment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Capital Investment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Direct Charges:								
Raw materials	$ 4,956.12	$ 4,956.12	$ 4,956.12	$ 4,956.12	$ 6,271.75	$ 6,271.75	$ 6,271.75	$ 6,271.75
Labor	$ 9,417.27	$ 9,417.27	$ 9,417.27	$ 9,417.27	$ 11,917.12	$ 11,917.12	$ 11,917.12	$ 11,917.12
Supervisor	$ 1,412.67	$ 1,412.67	$ 1,412.67	$ 1,412.67	$ 1,787.67	$ 1,787.67	$ 1,787.67	$ 1,787.67
Utilities	$ 2,957.33	$ 2,957.33	$ 2,957.33	$ 2,957.33	$ 3,742.37	$ 3,742.37	$ 3,742.37	$ 3,742.37
Maintenance	$ 1,972.08	$ 1,972.08	$ 1,972.08	$ 1,972.08	$ 2,495.58	$ 2,495.58	$ 2,495.58	$ 2,495.58
Operating Supplies	$ 295.42	$ 295.42	$ 295.42	$ 295.42	$ 373.84	$ 373.84	$ 373.84	$ 373.84
Lab	$ 1,412.67	$ 1,412.67	$ 1,412.67	$ 1,412.67	$ 1,787.67	$ 1,787.67	$ 1,787.67	$ 1,787.67
Patents	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Direct Product Cost	$ 22,423.56	$ 22,423.56	$ 22,423.56	$ 22,423.56	$ 28,375.99	$ 28,375.99	$ 28,375.99	$ 28,375.99

i 0.37571022

Year	PWF	ACF	REC	TCI	Net Worth	Present Worth
0	1	0	0	708320.93	-708320.93	-708320.93
1	0.72689727	124451.743	0	0	124451.743	90463.6318
2	0.52837964	205593.542	0	0	205593.542	108631.441
3	0.38407771	288660.402	0	0	288660.402	110868.027
4	0.27918504	352604.52	0	0	352604.52	98441.9072
5	0.20293884	371801.607	0	0	371801.607	75452.9877
6	0.14751569	398779.997	0	0	398779.997	58826.3065
7	0.10722875	426766.235	0	0	426766.235	45761.6107
8	0.07794429	448989.262	0	0	448989.262	34996.1478
9	0.05665749	472323.44	0	0	472323.44	26760.6601
10	0.04118417	496824.328	914351.31	0	1411175.64	58118.1028
					NPW	-0.1074119

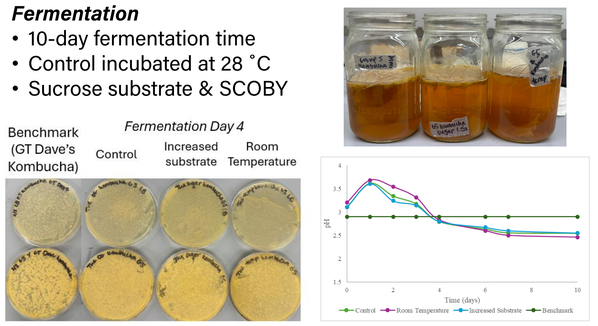
- Annual cash flow depends on the following values:
  - Inflation = 5%
  - 5 Year MACRS used to calculate depreciation
  - Iterative process used to find an i=0.375

Total Capital Investment: $118,428.51
Total Production Cost (Initial): $10,010.30 for initial 1000L batch
Total Production Cost (Final): $572.08 for all subsequent batches
Return of Investment: 0.375 or 37.5%
- Production Site Located in West Lafayette, Indiana

Experimental Results

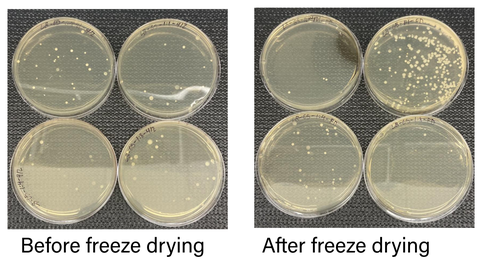
Fermentation

- 10-day fermentation time
- Control incubated at 28 ˚C
- Sucrose substrate & SCOBY



Freeze Drying

- Trehalose : fermentation product ratios tested: 0:1, 1:1, 1:4, 1:8



Before freeze drying | After freeze drying

Future Work

- Further test cryoprotectant to fermentation product ratios to minimize additional sugar as much as possible.
- Expand the probiotic diversity of the product by culturing additional strains with specific digestive and skin health benefit.
- Study shelf live stability of powder in stability chambers.

Acknowledgements & Special Thanks to…
Instructors: **Dr. Martin Okos & Daniel Hauersperger**
Technical Advisor: **Dr. Martin Okos**
Sponsor: **Agricultural & Biological Engineering Department**
***Equipment, Materials, & Lab Advising*: Mandy Limiac**
Poster Printing: **Carol Weaver**