PROJECT 3: MULTIPLE RESPONSE OPTIMIZATION IN BEER BREWING

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BACKGROUND

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- Barley, the most widely adapted cereal grain in the world, is an ancient crop that has been used for thousands of years for feed, food, and the production of beer.
- The process by which barley is converted into a usable form for brewing is called malting.

DEPENDENT VARIABLES (RESPONSES)

Response	Units
Amylase Level (Goal:Max)	(U/G)
Superoxide Dismutase (SOD) Level (Goal:Max)	(U/G)
Dymethyl Sulphide (DMS) (Target: 65 ppb)	Parts per Billion (ppb)

INDEPENDENT VARIABLES (FACTORS)

Factor	Minimum	Maximum
Seeping Temperature	14°C	18°C
Seeping Time	24 hours	48 hours
Germination Temperature	12°C	20°C
Hydrogen Peroxide	0 g/L	0.2 g/L
Germination Time	4 hours	8 hours
Withering Temperature	35°C	50°C
Drying Temperature	55°C	65°C
Kilning Temperature	70°C	90°C
IDK Level	1 Tufnel	11 Tufnels

METHODOLOGY

STAGE 1: VARIABLE SELECTION

- We conducted a variable screening experiment over entire feasible region.
- Using a Definitive Screening Design (with JMPs automatic formulation)
  - Because it does not alias main effects
  - Uses small number of design points
  - Correlation structure should have minimal impact on determinations
- Performed Stepwise selection for model parameters for each Response
- Purpose:
  - Identify main effects to include in model building

STAGE 2: MODEL BUILDING

- We fit model using a CCD, face-centered and four center-points.
  - Assumes variable reduction successful
  - High power relative to runs
  - Good *picture* of surface

STAGE 3: DATA ANALYSIS

- Using model runs from Stage 2, desirability functions are used to determine optimal points
  - Include both Additive and Multiplicative functions
  - Develop recommendation for Decision Maker

ANALYSIS: STAGE 1

VARIABLE SELECTION FOR AMYLASE LEVEL

Anova Table for reduced model for Amylase Level

	Estimate	Std. Error	t value	Pr(>|t|)
Steeping_Time	50.82	26.25	1.936	0.06973
Germination_Temp	80.67	26.25	3.073	0.006893
Kilning_Temp	165.9	26.25	6.32	7.679e-06
(Intercept)	733.8	24.31	30.19	3.287e-16

VARIABLE SELECTION FOR SOD LEVEL

Anova Table for reduced model for Superoxide Dismutase Level

	Estimate	Std. Error	t value	Pr(>|t|)
Steeping_Time	44.6	13.35	3.34	0.003883
Germination_Temp	153.6	13.35	11.5	1.92e-09
Kilning_Temp	-165.6	13.35	-12.4	6.066e-10
(Intercept)	937.4	12.36	75.81	5.934e-23

VARIABLE SELECTION FOR DMS

Anova Table for reduced model for Dymethyl Sulphide

	Estimate	Std. Error	t value	Pr(>|t|)
Steeping_Time	7.4	1.4	5.4	4.9e-05
Germination_Temp	21	1.4	15	3.1e-11
IDK_Level	2.1	1.4	1.5	0.15
(Intercept)	38	1.3	30	4.5e-16

Anova Table for reduced model for absolute value of Dymethyl Sulphide

	Estimate	Std. Error	t value	Pr(>|t|)
Steeping_Time	-4.982	1.118	-4.458	0.0003042
Germination_Temp	-18.17	1.118	-16.26	3.334e-12
(Intercept)	29.44	1.035	28.46	2.036e-16

ANALYSIS: STAGE 2

MODEL FOR AMALYSE

Anova Table For Amylase Level

	Estimate	Std. Error	t value	Pr(>|t|)
Steep_Time	38	21	1.8	0.097
Germ_Temp	-121	21	-5.8	9.1e-05
Kiln_Temp	138	21	6.6	2.7e-05
I(Germ_Temp^2)	-90	32	-2.8	0.015
Steep_Time:Germ_Temp	45	24	1.9	0.078
(Intercept)	975	24	41	2.5e-14

MODEL FOR SOD LEVEL

Anova Table For SOD Level

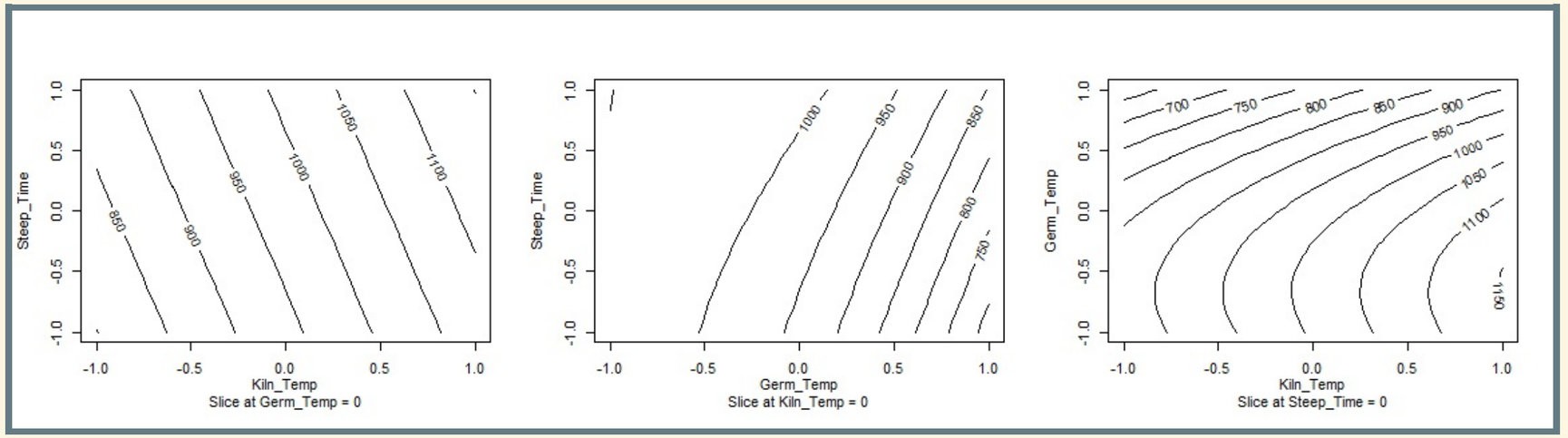
	Estimate	Std. Error	t value	Pr(>|t|)
Steep_Time	-52	18	-2.9	0.013
Germ_Temp	114	18	6.5	4.6e-05
Kiln_Temp	-146	18	-8.3	4.6e-06
I(Germ_Temp^2)	51	26	1.9	0.081
Steep_Time:Germ_Temp	-61	20	-3.1	0.01
Steep_Time:Kiln_Temp	-36	20	-1.8	0.095
(Intercept)	1029	20	52	1.6e-14

MODEL FOR DSD DISTANCE

Anova Table For DSD Distance from 65

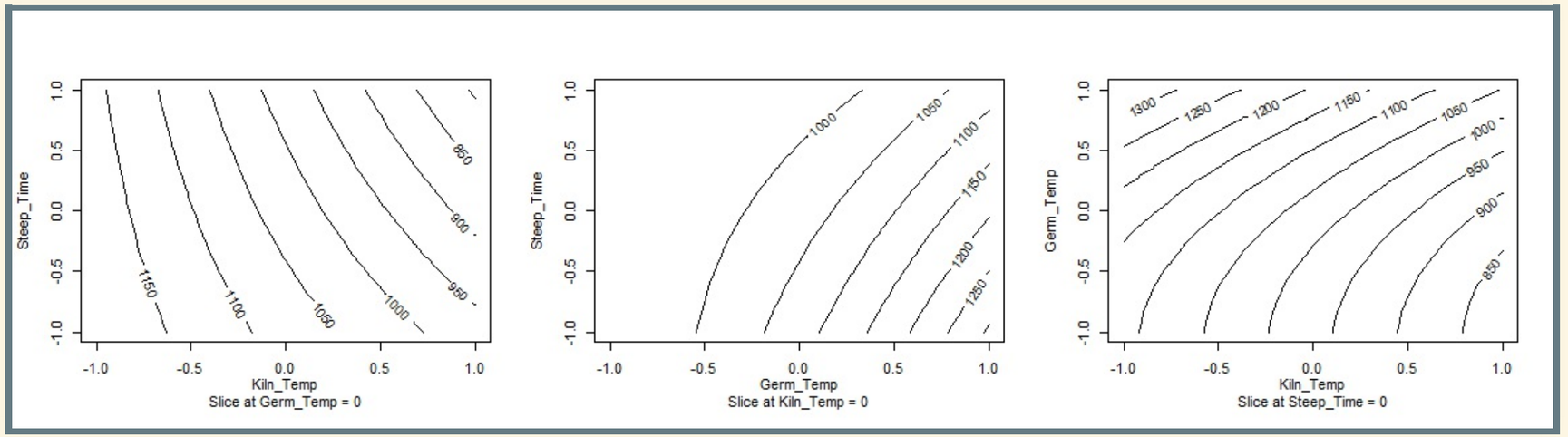
	Estimate	Std. Error	t value	Pr(>|t|)
Steep_Time	-1	1.3	-0.8	0.44
Germ_Temp	-8.3	1.3	-6.5	1.4e-05
I(Steep_Time^2)	4.8	1.9	2.5	0.026
(Intercept)	10	1.4	7	6.7e-06

RESULTING SURFACE PLOTS



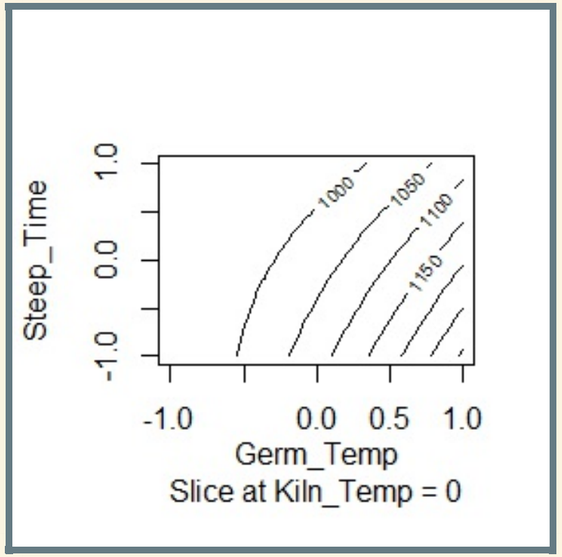
Contour Plots for Amylase

RESULTING SURFACE PLOTS



Contour Plots for SOD

RESULTING SURFACE PLOTS

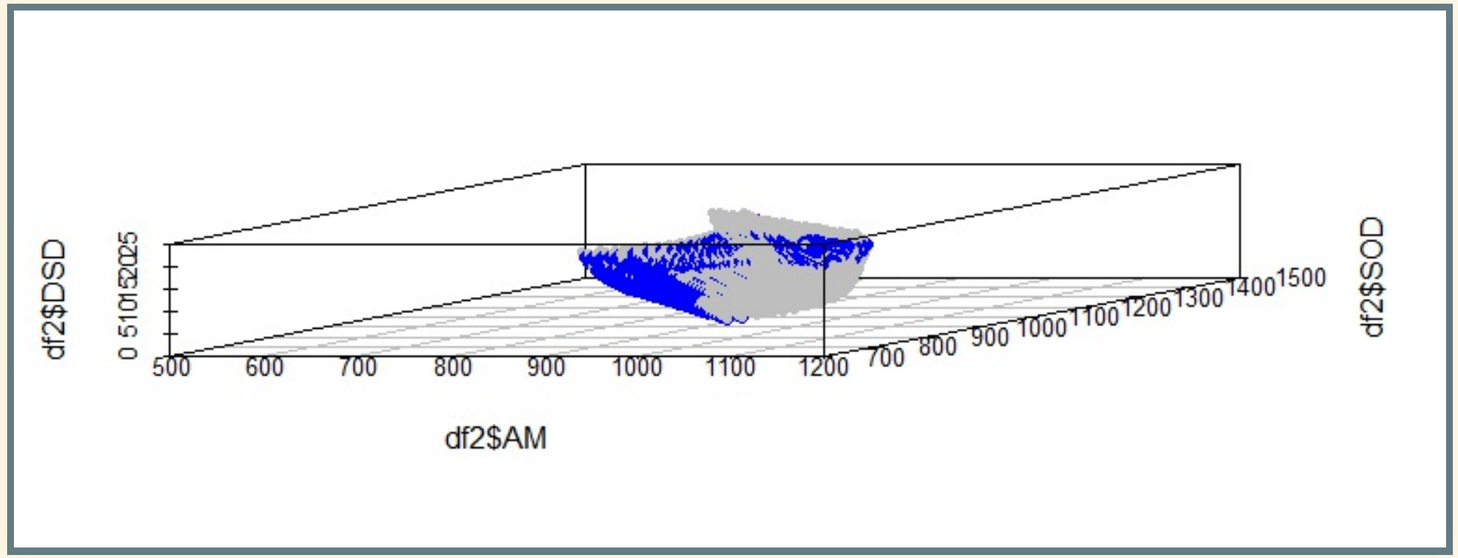


Contour Plots for DSD

ANALYSIS: STAGE 3

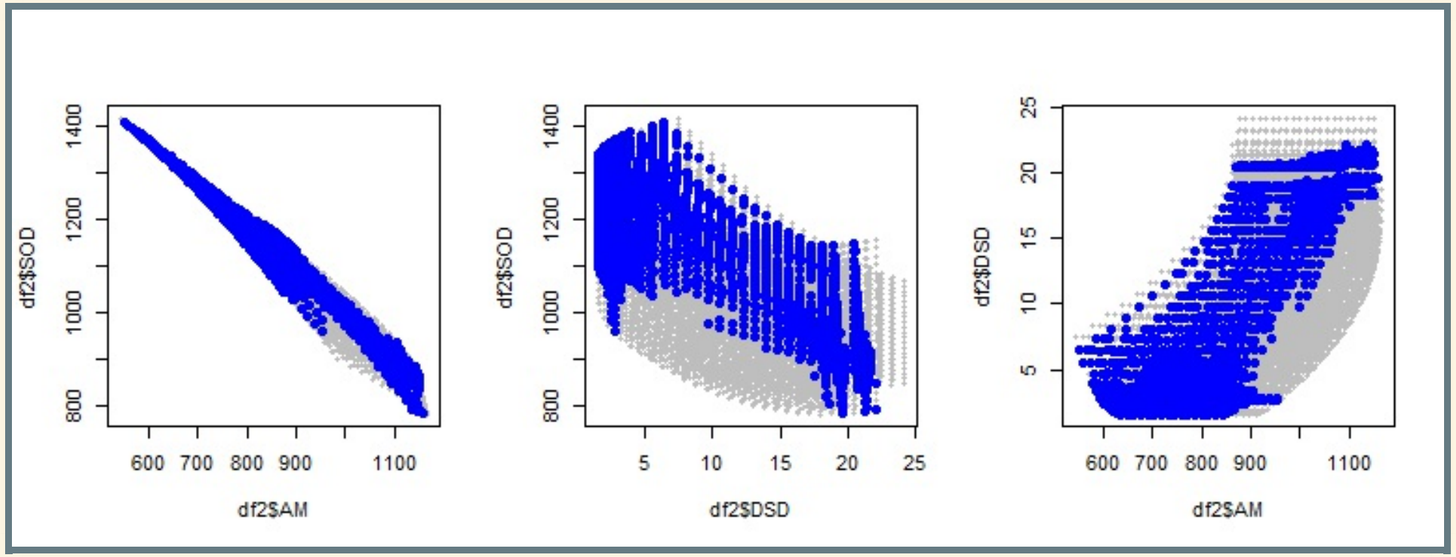
PARETO FRONT

- 9261 observations (0.1 incriments on each variable)
- The Pareto Front reduced this to 1621 observations



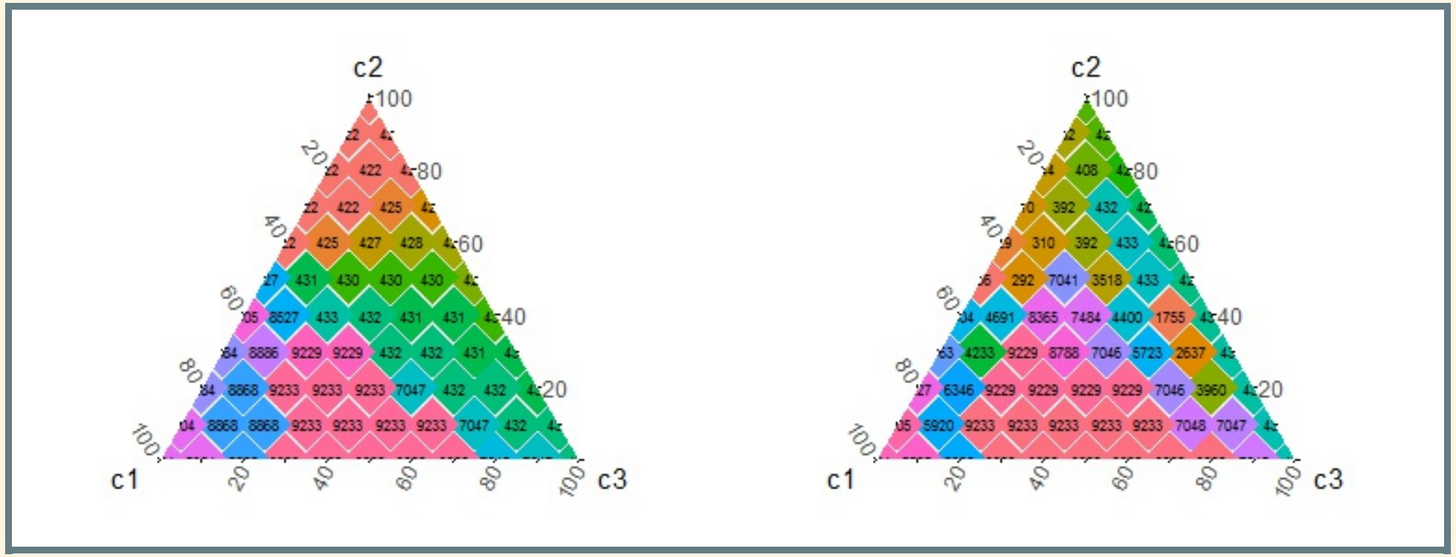
3D Scatter Plot of Pareto Front, blue points are on the Pareto Front

PARETO IN 2D



Projections of pareto front into 2D, blue points are on the pareto front

MIXTURE PLOTS



Additive and Multiplicative Mixture Plots

MORE ON MIXTURES

- Mixture plots don’t give a great picture. The tables below show the top five observations in overall percentage of plots above

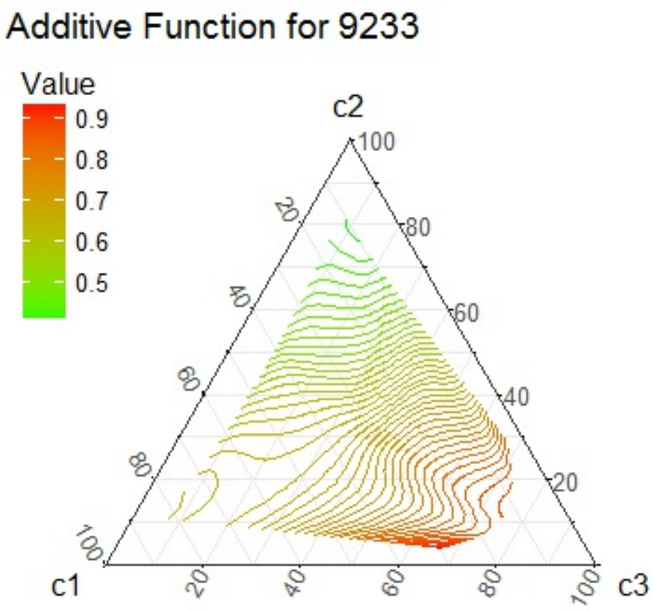
5 best addative scores

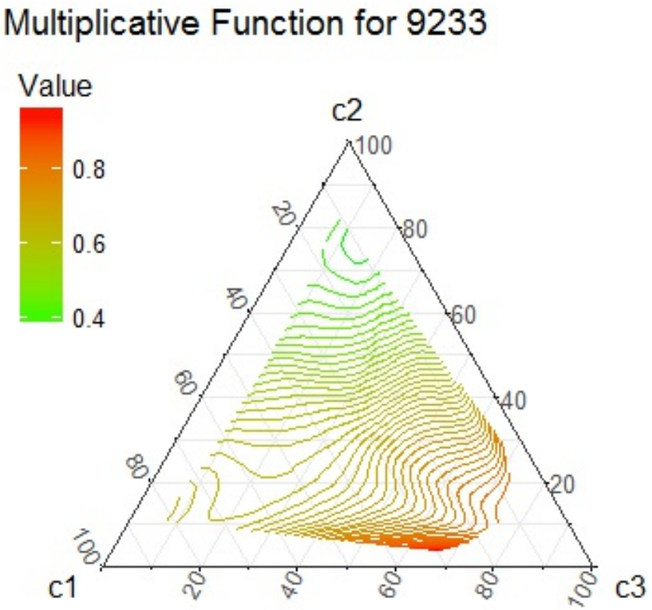
9233	**422**	**432**	**431**	**430**
0.18	0.14	0.12	0.091	0.061

5 best multiplicative scores

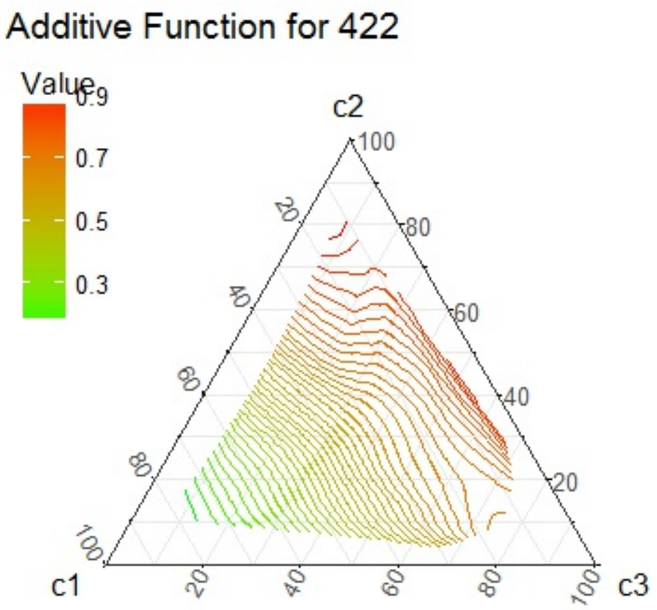
9233	**9229**	**432**	**310**	**392**
0.17	0.076	0.045	0.03	0.03

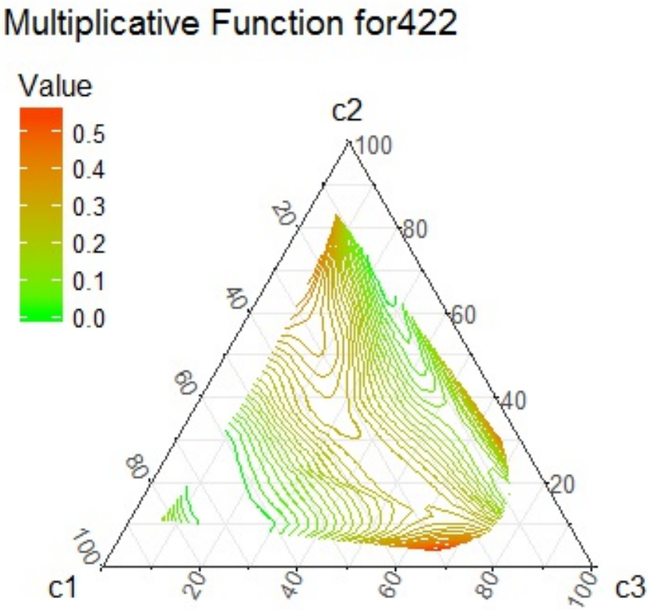
CONTOUR FOR POINT 9233



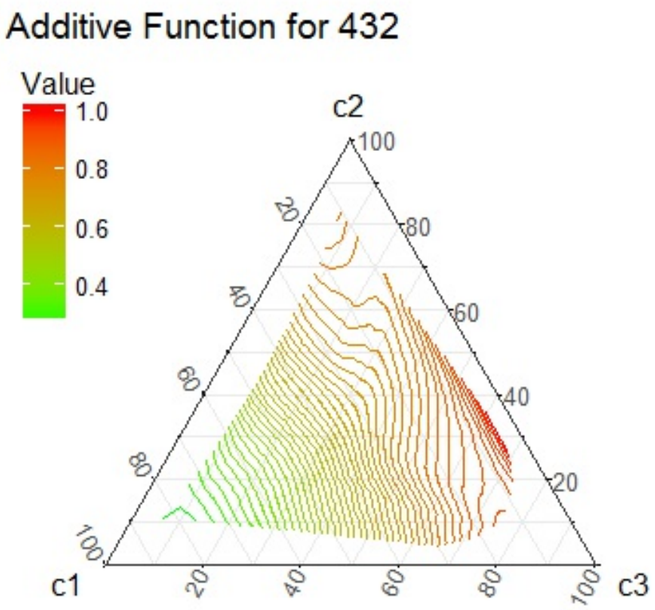


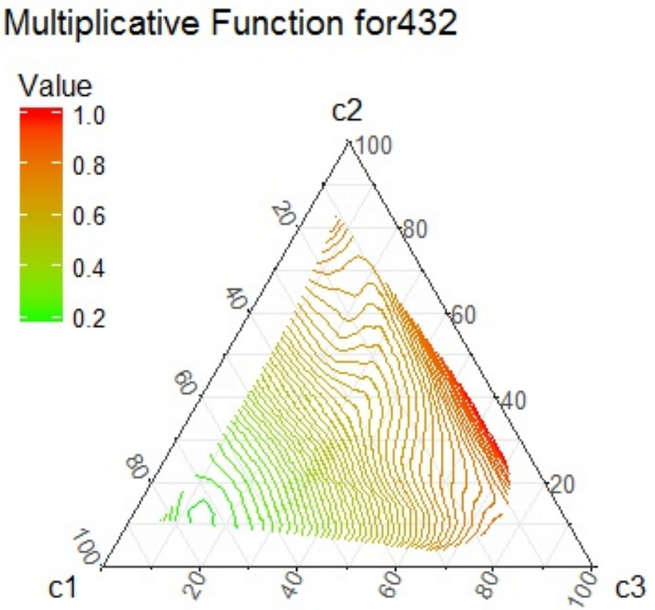
CONTOUR FOR POINT 422





CONTOUR FOR POINT 432





VALUES OF SELECTED POINTS

Table values for Point 9233

	Steep_Time	Germ_Temp	Kiln_Temp	AM	SOD	DSD
9233	0.3	0.9	1	0.66	0.32	0.95

Table values for Point 432

	Steep_Time	Germ_Temp	Kiln_Temp	AM	SOD	DSD
432	0.1	1	-1	0.14	0.88	1

CONCLUSIONS

RECOMMENDED POINT

- Considering that the points perform equally well, the reccomendation is to operate at the values associated with point 9233. This point achieves similar results with less sacrifices in each of the Response Variables.
- Steeping Time 39.6 hours, Germination Temperature of 19.6°C, and a Kilning Temperature of 90°C, all others at mean values.

CONFIRMATION

	AM	SOD	DSD
Rep1	1055.32	971.74	60.6
Rep2	1033.41	959.68	63.37
Rep3	1000.57	984.23	64.07
Rep4	1055.52	936.23	58.51
Model	1043.976	983.3642	6.06584
avg	1036.205	962.97	3.3625
Sdev.s	25.92372	20.45118	2.567507
Tstat	0.299749	0.997211	1.052905

L2

- Large number of factors works against simplicity of design
  - Strong methodology can overcome (TWI vs. FO)
  - More variables = More noise
- Progressive approach to analysis
  - First Order model then Second Order model
  - Discussion of Tradeoffs

QUESTIONS

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