



Dutch Cocoa Brownies

3-factor DOE

(Design of Experiment)

-truncated for general viewing

Pat Neyman

DOE Background

- DOE is a statistical tool used to understand the effects that certain variables and their interactions may have on a desired system
- Statistical design provides for economy and efficiency in research, development, and production
- Primary advantages of using DOE
 - Optimizing a process
 - Generating models of a system for predicted responses

Important Terminology

- **Factor(s)** - the variable being investigated
- **Response(s)** - the measured product or outcome of the process suspected to be influenced by the experimental factors studied
- **Interaction(s)** - the effect that occurs when the combined change in two factors produces an effect greater (or less) than that of the sum of effects expected from either factor alone
- **Factorial** - A series of runs in which combinations of factor levels are included

Experimental Factors

(units are standard kitchen measurements)

- **Time Cooked**
3 levels: 10 min., 20 min., 30 min.
- **Rack Position**
Distance from lower element (heating element)
3 levels: 3.5 in., 5.0 in., 9.0 in.
- **Fat Content of Fatty Agent**
units in g / Tbsp. (cooking convention)
- » **Temperature measured with mercury oven thermometer at lowest rack position, middle of rack.**

Brownie Recipe

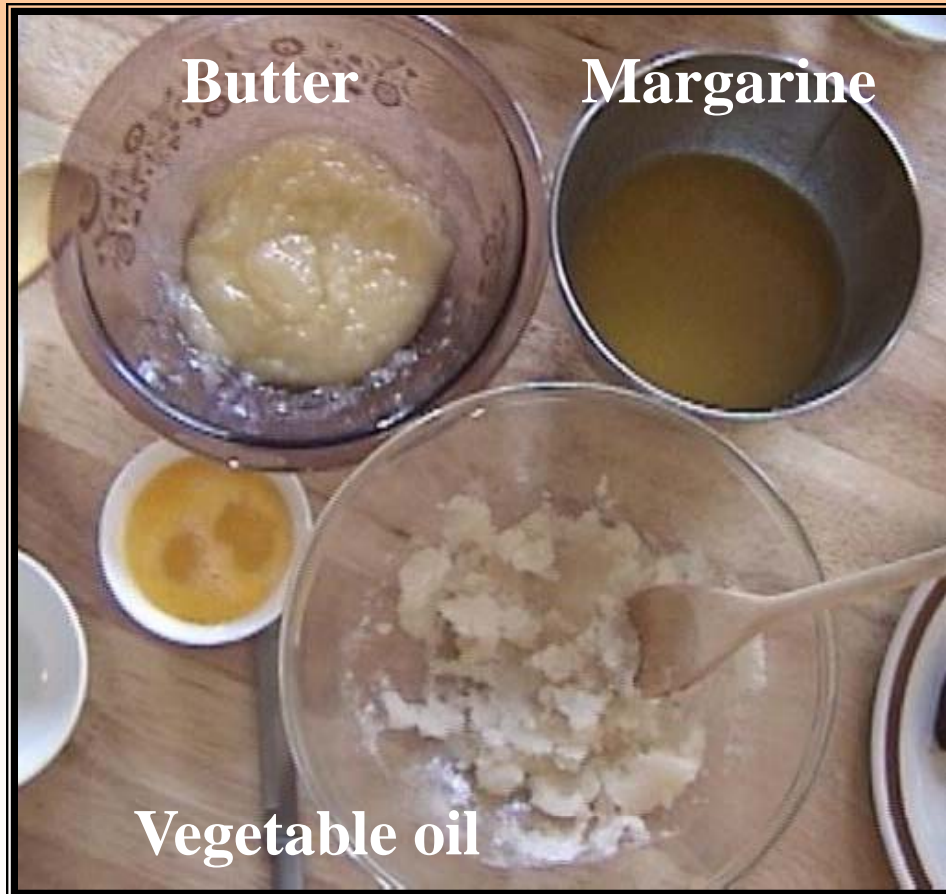
- 1 c. Fatty agent
- 2 c. sugar
- 2 tsp. vanilla extract
- 4 eggs
- 1 c. flour
- 3/4 c. Hershey's Dutch processed cocoa
- 1/2 tsp. Baking powder
- 1/4 tsp. salt

- Grease pan (Pam)
- Combine sugar, vanilla in liquid fatty agent
- Add egg slowly, beating with spoon
- Add remaining ingredients
- Beat until blended
- Bake at 350°F

Fatty Agent Parameters

| Fatty Agent | Total Fat (g / Tbsp) | Saturated Fat (g / Tbsp) |
|--------------------|-------------------------|-----------------------------|
| Vegetable Oil | 14 | 1.5 |
| Butter | 11 | 8 |
| Light Margarine | 5 | 1 |

Fatty Agent with Sugar and Vanilla



- Equal amounts of each fatty agent: vegetable oil, butter, margarine
- No variation of other ingredients
- Obvious correlation between fat content and viscosity

Conventional Baking Device



- 1970's model
“Kitchen Maid” dual-element convention oven with 3-rack height adjustability

Visual Results



Example of a
“mushy” sample



Appearance of soft
and rigid brownies
have little distinction



High fat content
brownies tend to
flatten

Responses

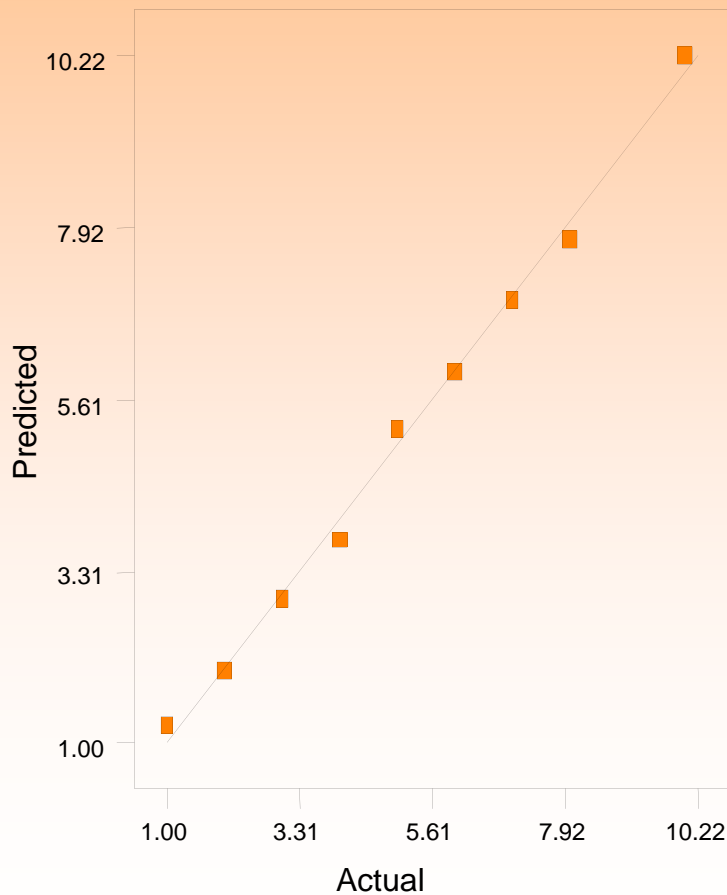
(All on scale from 1 to 10)

- **Rigidity** (2-Level Factorial)
<2 is liquid state, >8 is solid state.
- **Chewiness** (2-Level Factorial)
<2 melts in mouth, >8 chewy until the end.
- **Crustiness** (Linear)
2 is very thin layer, 5 is crisp layer, >8 solid state.
- **Chocolate Richness** (Linear)
<2 can barely taste chocolate, >8 is overwhelming.

Rigidity Response (2LF)

No Interaction between Time Cooked and Rack Position
Rack Position makes Little Difference

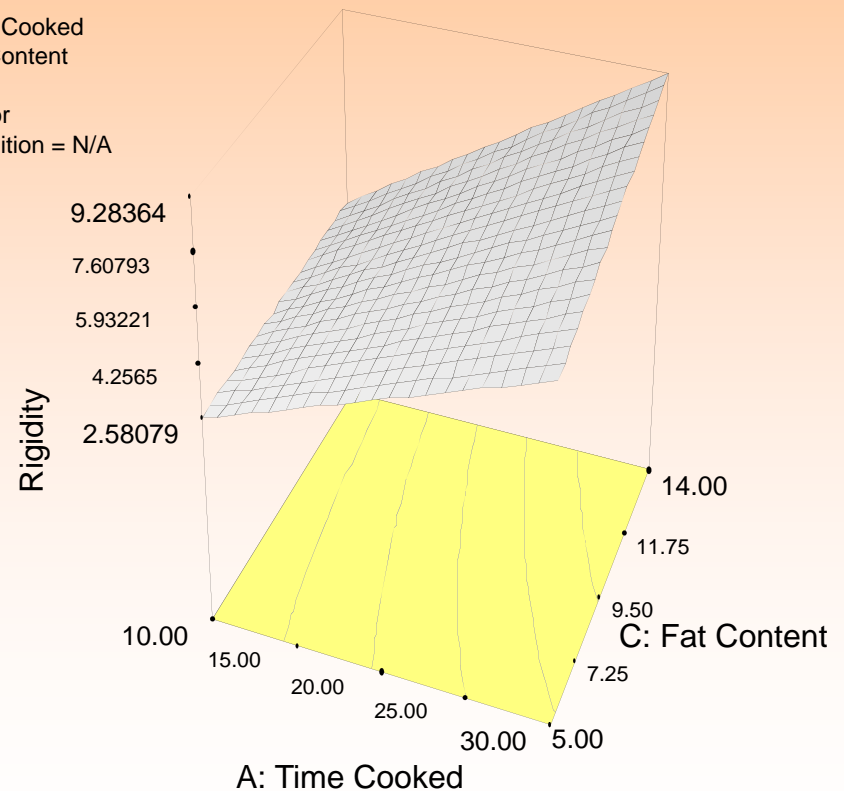
Predicted vs. Actual



DESIGN-EXPERT Plot

Rigidity
X = A: Time Cooked
Y = C: Fat Content

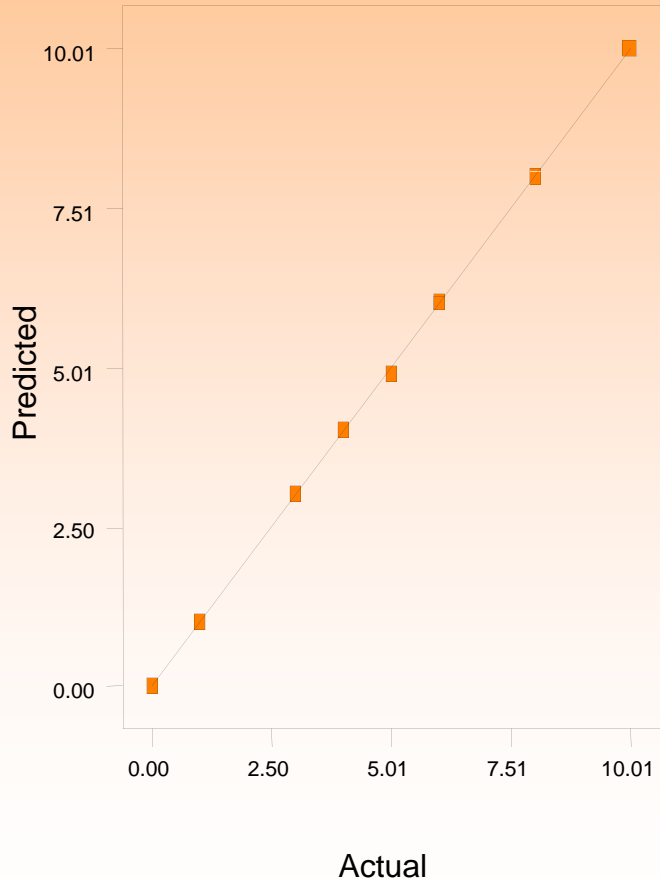
Actual Factor
B: Rack Position = N/A



Chewiness Response (2LF)

All Responses Interact -- Time Cooked is Largest Factor
(Fat Content makes Little Difference)

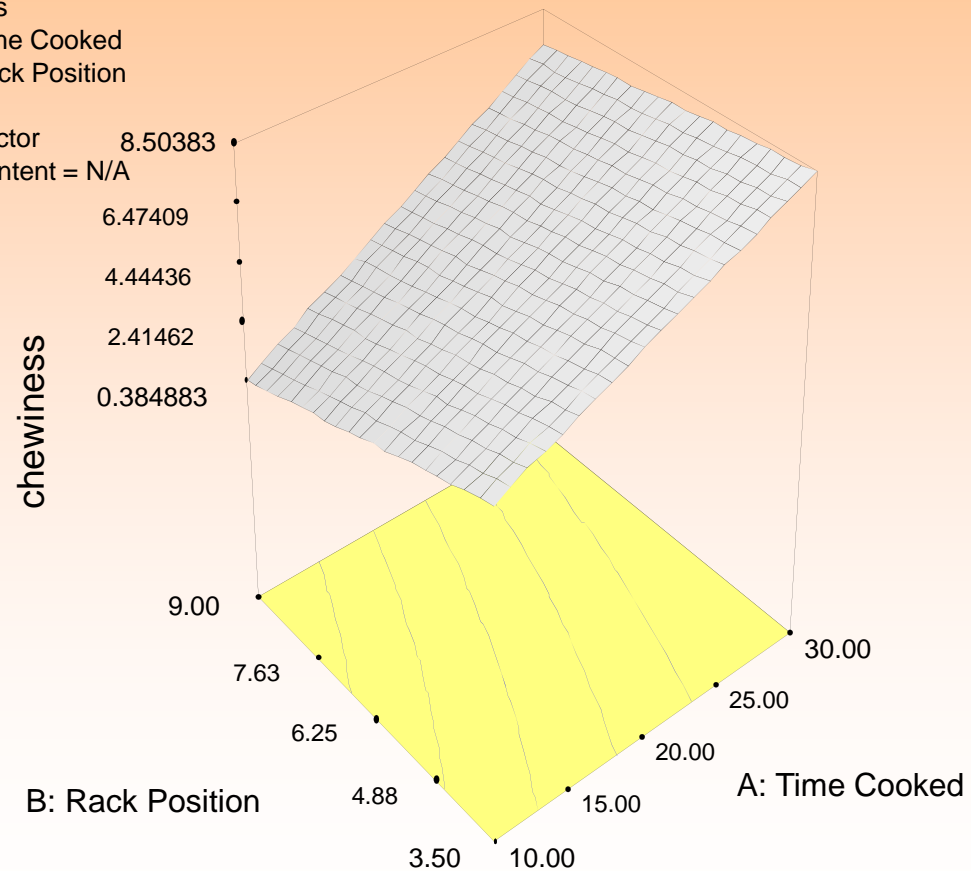
Predicted vs. Actual



DESIGN-EXPERT Plot

chewiness
X = A: Time Cooked
Y = B: Rack Position

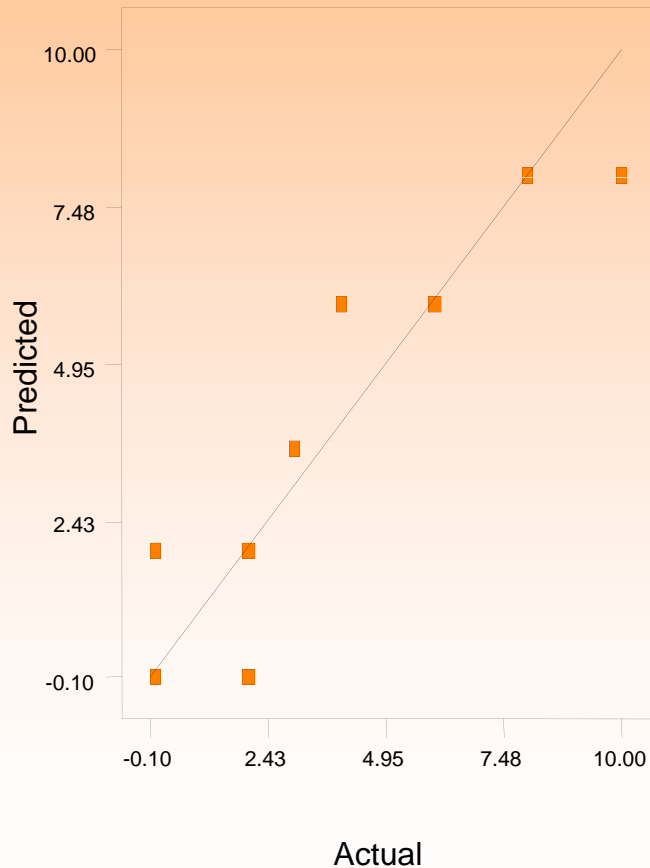
Actual Factor 8.50383
C: Fat Content = N/A



Crustiness Response (Linear)

Rack Position Not a Factor

Predicted vs. Actual



DESIGN-EXPERT Plot

Crustiness

● Design Points

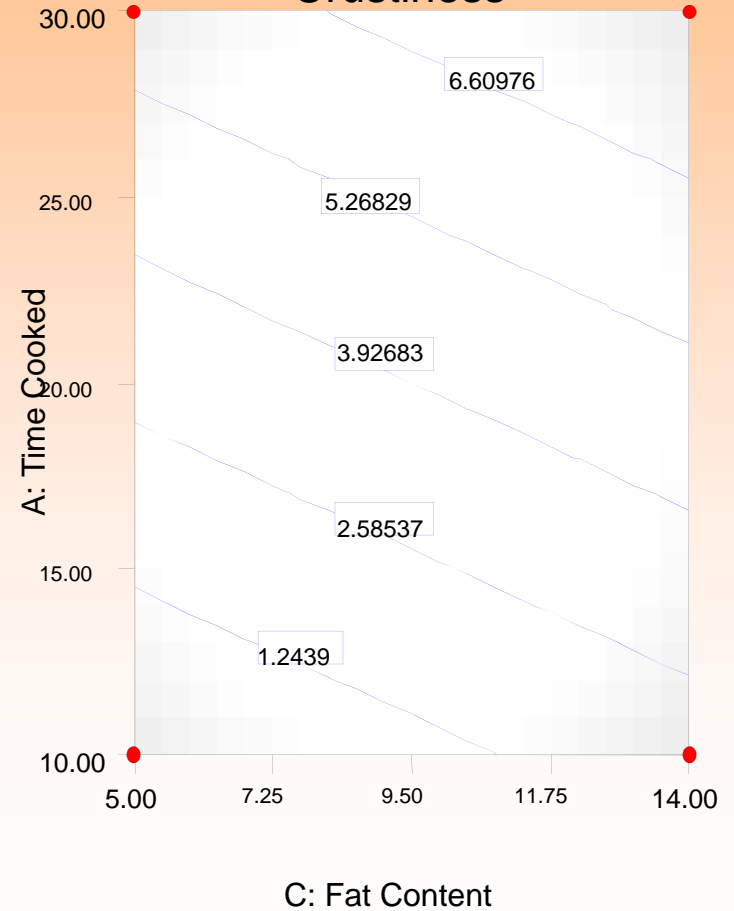
X = C: Fat Content

Y = A: Time Cooked

Actual Factor

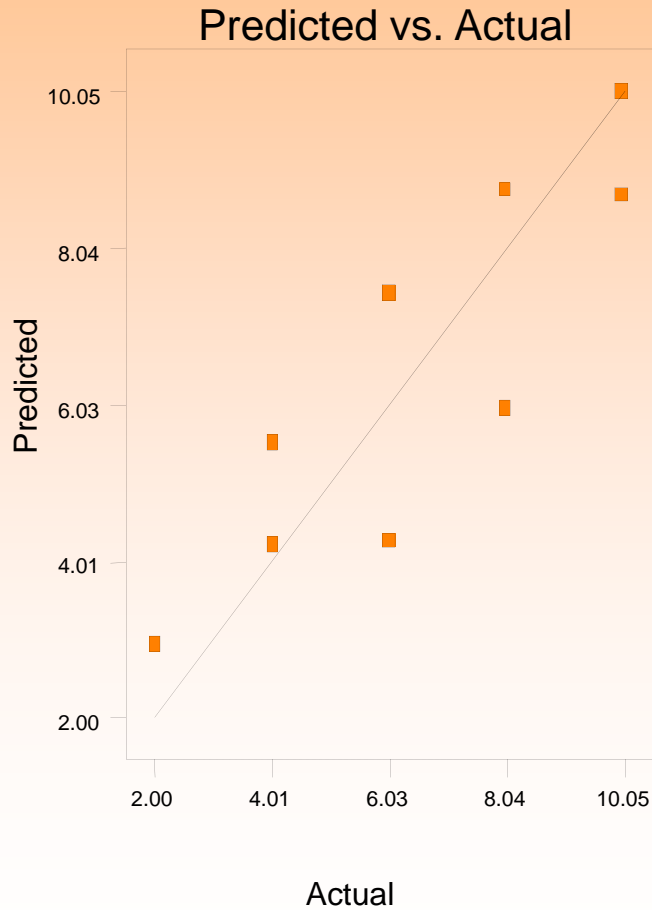
B: Rack Position =N/A

Crustiness



Chocolate Richness Response (Linear)

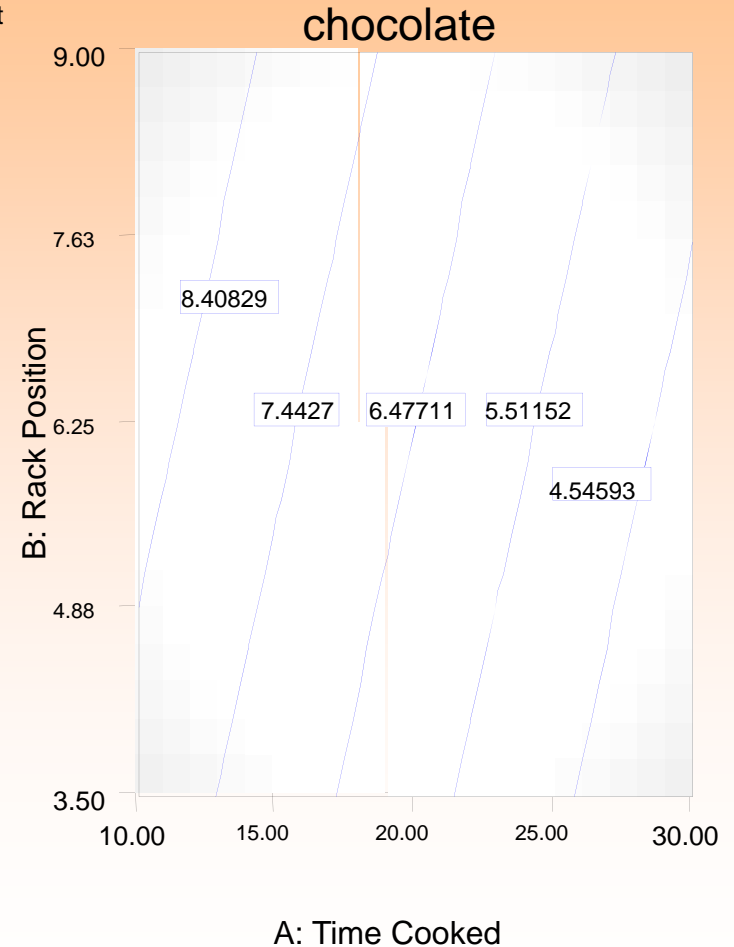
Fat Content Not a Factor (Although Butter adds a Taste Quality)



DESIGN-EXPERT Plot

chocolate
X = A: Time Cooked
Y = B: Rack Position

Actual Factor
C: Fat Content = N/A



Focus Group's Preferred Brownie

(Optimization Criteria)

- Fairly rich chocolate flavor: 7 - 9
- Pleasantly chewy: 4 - 7
- Crustiness more than light,
but not too hard: 3 - 5
- Rigidity not too important.
Neither a rock, nor a river: 3 - 8

Light Margarine Just Won't Do

DESIGN-EXPERT Plot

Overlay Plot

● Design Points

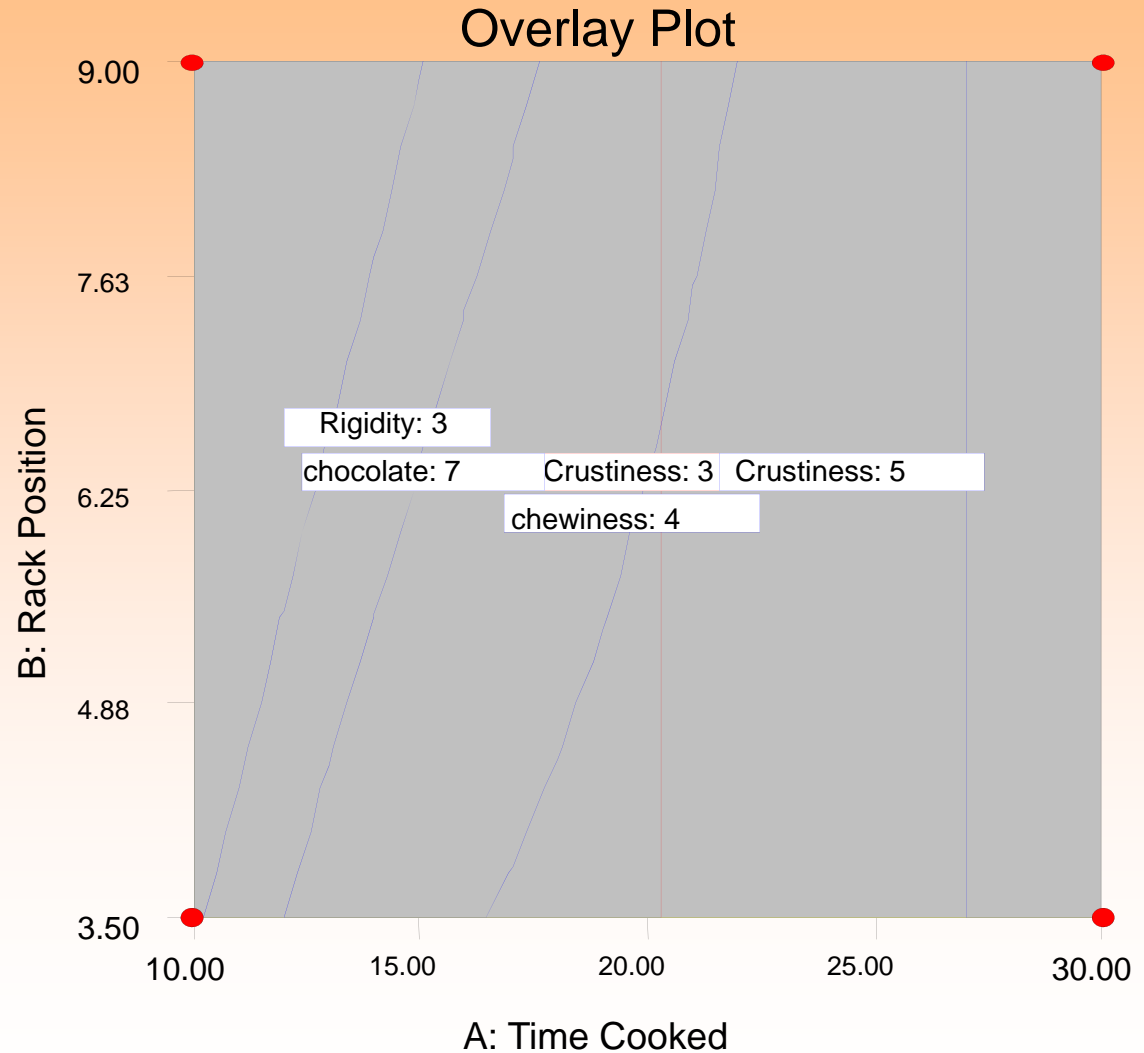
X = A: Time Cooked

Y = B: Rack Position

Actual Factor

C: Fat Content = 5.00

Minimum fat
content threshold
for our taste is 9.5
g /Tbsp.



Butter Gives a Comfortable Range of Options

DESIGN-EXPERT Plot

Overlay Plot

X = A: Time Cooked

Y = B: Rack Position

Actual Factor

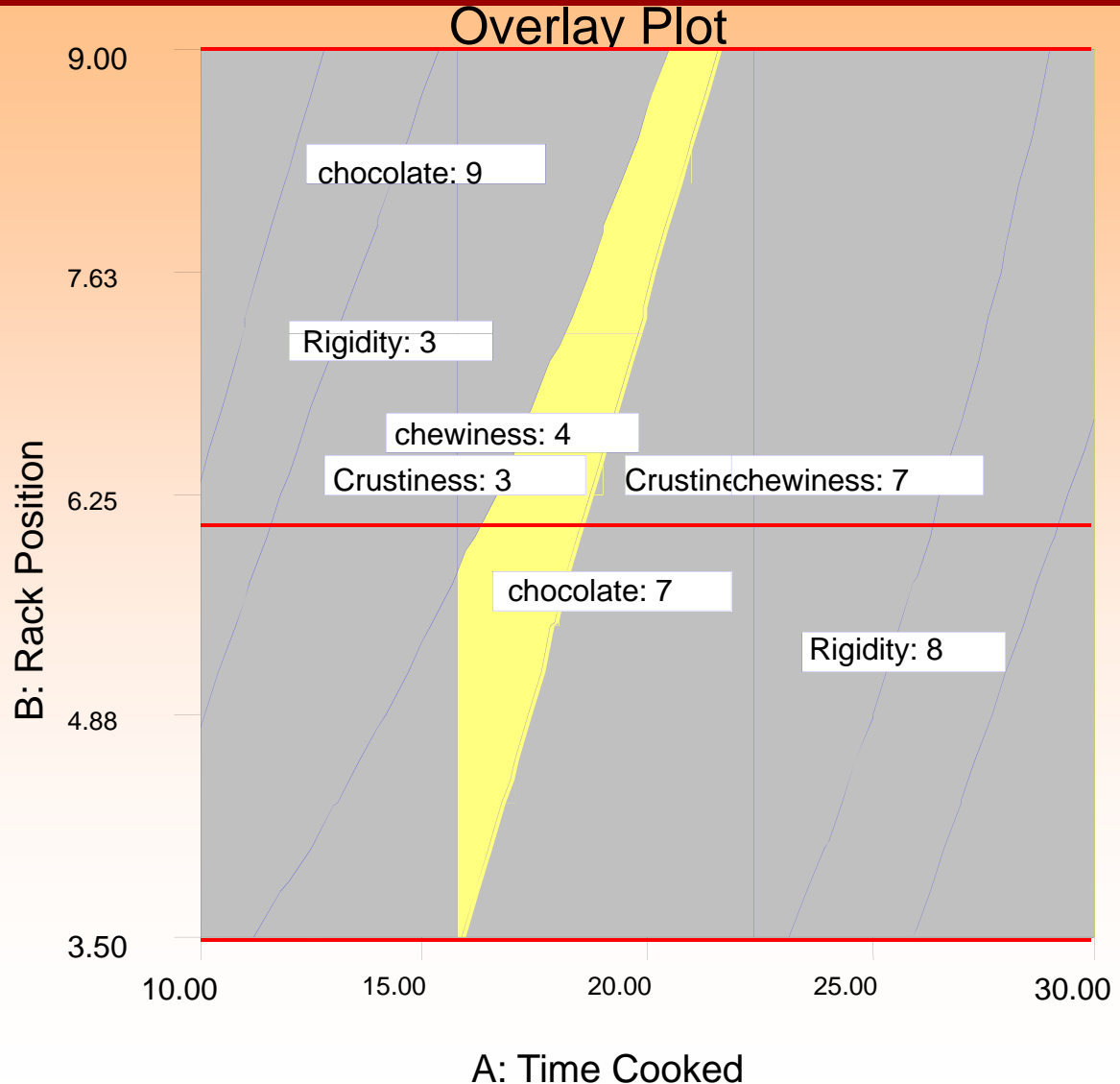
C: Fat Content = 11.08

Crustiness is vertical, and a left border

Chewiness border on left

Chocolate border on right

Rigidity not a factor



Vegetable Oil Affords Widest Range of Options

DESIGN-EXPERT Plot

Overlay Plot

● Design Points

X = A: Time Cooked

Y = B: Rack Position

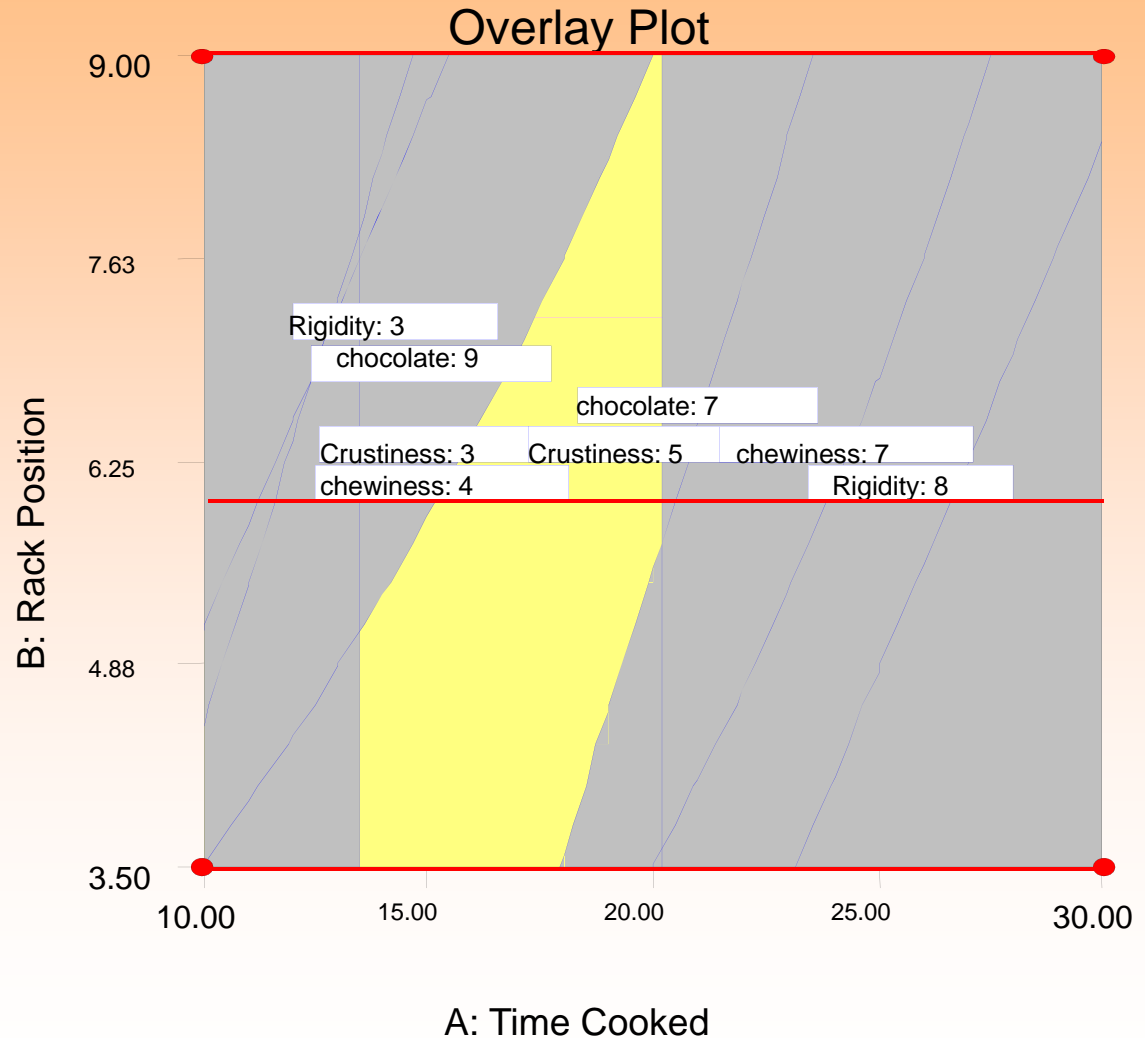
Actual Factor

C: Fat Content = 14.00

Chewiness &
Crustiness left
border again

Crustiness joins
right border with
Chocolate

Rigidity still not a
factor



Focus Group Conclusions

- Rigidity eliminated as factor: Chewiness is better since it is something you can “sink your teeth into”
- Interactions occur only for Chewiness, which is governed primarily by Time Cooked
- Surprisingly, Fat Content does not affect Richness of Chocolate (Although butter has a nice intrinsic flavor)
- Fat Content affects only Crustiness, for which rack position is not a factor
- Highest Fat Content (Vegetable Oil) mixture affords greatest flexibility of cooking factors
- Low Fat Content (Light Margarine) does not produce chewy brownies with acceptable palate