R Codes Used for X1 PP/SP CASE STUDY—Beer Glasses

Examples are provided below using the *Foam Height* attribute for the twelve beer glasses from the PP/SP case study.

R packages lme4 and lmerTest are used for analyses.

Excel and the lmerTest plot function were used for plotting.

beerglassdata.xlsx

Datasheet: Data

|  |  |
| --- | --- |
| **Variable** | **Values** |
| glass | 1-12 |
| code | 3-digit code |
| assessor | 1-8 |
| replicate | 1-2 |
| wrap | yes or no |
| stage | top, middle, bottom |
| FoamHeight | 0-20 point scale |
| A.CO2 | 0-100 point scale |
| A.Hops | 0-100 point scale |
| A.Malt | 0-100 point scale |
| F.CO2 | 0-100 point scale |
| F.Hops | 0-100 point scale |
| F.Malt | 0-100 point scale |
| F.Sweet | 0-100 point scale |
| F.Sour | 0-100 point scale |
| F.Bitter | 0-100 point scale |
| Coldness | 0-100 point scale |

STEP 1: Mixed Model

1A) Import and format data file; convert fixed and random effects to factors

> library(xlsx)

> beerglassdata <- read.xlsx(file="c://data//beerglassdata.xlsx", header=T, sheetName="Data")

> head(beerglassdata)

glass code assessor replicate wrap stage FoamHeight A.CO2 A.Hops A.Malt F.CO2 F.Hops F.Malt F.Sweet F.Sour F.Bitter Coldness

1 1 163 1 1 no top 7 27 50 39 39 50 42 25 37 52 55

2 1 163 2 1 no top 7 20 48 40 39 50 40 21 40 49 63

3 1 163 3 1 no top 3 39 51 39 40 49 39 19 39 49 53

4 1 163 4 1 no top 5 27 48 38 34 49 41 30 46 53 57

5 1 163 5 1 no top 7 24 49 32 55 46 45 24 28 49 67

6 1 163 6 1 no top 7 33 49 40 49 59 41 23 39 56 57

> beerglassdata[,"glass"] <- as.factor(beerglassdata[,"glass"])

> beerglassdata[,"assessor"] <- as.factor(beerglassdata[,"assessor"])

> beerglassdata[,"replicate"] <- as.factor(beerglassdata[,"replicate"])

> beerglassdata[,"wrap"] <- as.factor(beerglassdata[,"wrap"])

> beerglassdata[,"stage"] <- as.factor(beerglassdata[,"stage"])

1B) Run lmer function; include 2-way interaction random and fixed effects in the model

> library(lme4)

> library(lmerTest)

> wmixedFoamHeight <- lmer(FoamHeight~glass+stage+wrap +glass:stage+ glass:wrap +

stage:wrap +(1|assessor)+(1|replicate)+(1|assessor:replicate)+(1|glass:assessor)+

(1|glass:replicate)+(1|wrap:assessor) + (1|wrap:replicate) + (1|stage:assessor) +

(1|stage:replicate), data=beerglassdata)

1C) Generate anova results of fixed effects

> anova(wmixedFoamHeight)

Type III Analysis of Variance Table with Satterthwaite's method

Sum Sq Mean Sq NumDF DenDF F value Pr(>F)

glass 49.02 4.457 11 12.96 2.9471 0.03393 \*

stage 457.64 228.819 2 8.28 151.3116 3.046e-07 \*\*\*

wrap 1.68 1.681 1 983.00 1.1113 0.29206

glass:stage 371.27 16.876 22 983.00 11.1596 < 2.2e-16 \*\*\*

glass:wrap 87.82 7.984 11 983.00 5.2793 3.813e-08 \*\*\*

stage:wrap 1.88 0.941 2 983.00 0.6222 0.53695

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

1D) Generate results of random effects

> rand(wmixedFoamHeight)

ANOVA-like table for random-effects: Single term deletions

Model:

FoamHeight ~ glass + stage + wrap + (1 | assessor) + (1 | replicate) + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | wrap:assessor) + (1 | wrap:replicate) + (1 | stage:assessor) + (1 | stage:replicate) + glass:stage + glass:wrap + stage:wrap

npar logLik AIC LRT Df Pr(>Chisq)

<none> 60 -1932.7 3985.3

(1 | assessor) 59 -1932.9 3983.8 0.523 1 0.4695442

(1 | replicate) 59 -1932.7 3983.4 0.044 1 0.8334293

(1 | assessor:replicate) 59 -1939.9 3997.8 14.537 1 0.0001374 \*\*\*

(1 | glass:assessor) 59 -1934.8 3987.7 4.367 1 0.0366422 \*

(1 | glass:replicate) 59 -1942.0 4002.0 18.723 1 1.512e-05 \*\*\*

(1 | wrap:assessor) 59 -1932.7 3983.3 0.000 1 0.9991235

(1 | wrap:replicate) 59 -1932.7 3983.3 0.000 1 1.0000000

(1 | stage:assessor) 59 -1972.2 4062.5 79.179 1 < 2.2e-16 \*\*\*

(1 | stage:replicate) 59 -1936.0 3990.1 6.756 1 0.0093416 \*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

1E) Use step function to select the best model

> mm.stepwmixedFoamHeight<- step(wmixedFoamHeight)

> mm.stepwmixedFoamHeight

Backward reduced random-effect table:

Eliminated npar logLik AIC LRT Df Pr(>Chisq)

<none> 60 -1932.7 3985.3

(1 | wrap:replicate) 1 59 -1932.7 3983.3 0.000 1 1.000000

(1 | wrap:assessor) 2 58 -1932.7 3981.3 0.000 1 0.999818

(1 | replicate) 3 57 -1932.7 3979.4 0.044 1 0.833429

(1 | assessor) 4 56 -1932.9 3977.9 0.510 1 0.475113

(1 | assessor:replicate) 0 55 -1940.8 3991.5 15.637 1 7.676e-05 \*\*\*

(1 | glass:assessor) 0 55 -1935.2 3980.3 4.438 1 0.035151 \*

(1 | glass:replicate) 0 55 -1942.3 3994.7 18.828 1 1.430e-05 \*\*\*

(1 | stage:assessor) 0 55 -1974.0 4058.0 82.120 1 < 2.2e-16 \*\*\*

(1 | stage:replicate) 0 55 -1936.5 3982.9 7.039 1 0.007975 \*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Backward reduced fixed-effect table:

Degrees of freedom method: Satterthwaite

Eliminated Sum Sq Mean Sq NumDF DenDF F value Pr(>F)

stage:wrap 1 1.88 0.9410 2 983.83 0.6225 0.5368

glass:stage 0 371.27 16.8759 22 985.83 11.1721 < 2.2e-16 \*\*\*

glass:wrap 0 87.82 7.9836 11 985.83 5.2853 3.708e-08 \*\*\*

---

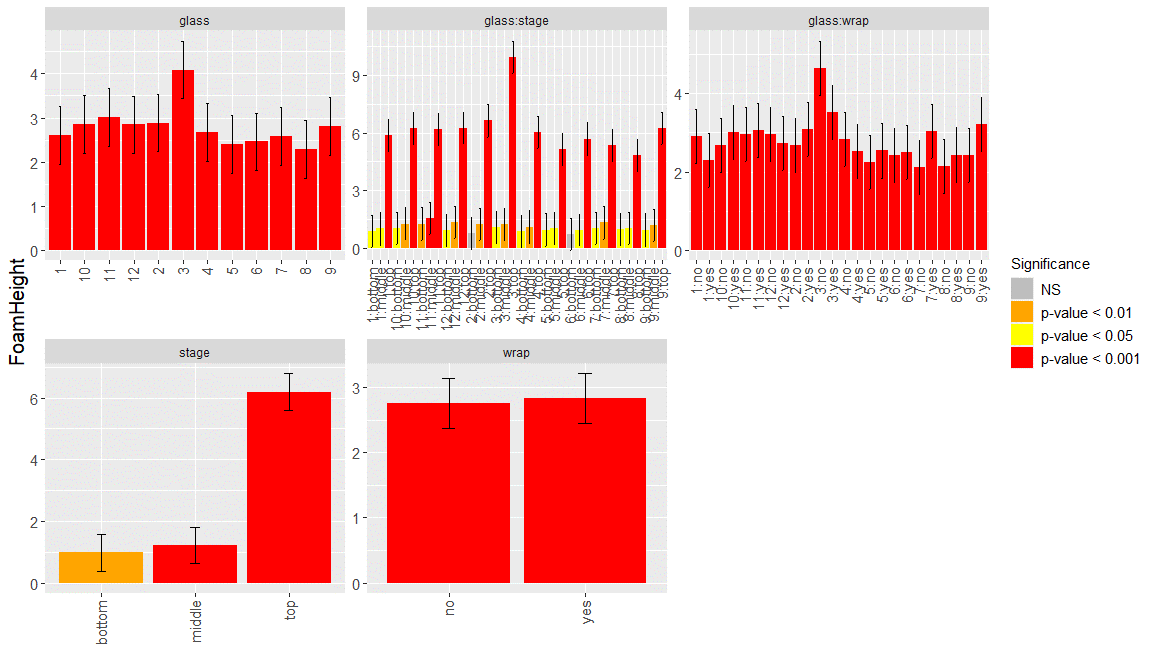
Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Model found:

FoamHeight ~ glass + stage + wrap + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | stage:assessor) + (1 | stage:replicate) + glass:stage + glass:wrap

1F) Plot output of step function to graphically show results of paired comparisons

> plot(mm.stepwmixedFoamHeight)



1G) Generate lsmeans for plots and paired comparisons

>gm.mm.stepwmixedFoamHeight <- get\_model(mm.stepwmixedFoamHeight)

#ALL LSMEANS VALUES

>lsdf.mm.stepwmixedFoamHeight <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight)))

> lsdf.mm.stepwmixedFoamHeight[1:17,]

term levels Estimate Std. Error df t value lower upper Pr(>|t|)

glass1 glass 1 2.6041667 0.3138825 21.67878 8.296628 1.9526545 3.255679 3.589358e-08

glass2 glass 2 2.8854167 0.3138825 21.67878 9.192664 2.2339045 3.536929 6.229794e-09

glass3 glass 3 4.0833333 0.3138825 21.67878 13.009113 3.4318211 4.734846 1.027154e-11

glass4 glass 4 2.6770833 0.3138825 21.67878 8.528934 2.0255711 3.328596 2.256722e-08

glass5 glass 5 2.3958333 0.3138825 21.67878 7.632898 1.7443211 3.047346 1.406103e-07

glass6 glass 6 2.4583333 0.3138825 21.67878 7.832017 1.8068211 3.109846 9.277484e-08

glass7 glass 7 2.5833333 0.3138825 21.67878 8.230255 1.9318211 3.234846 4.103632e-08

glass8 glass 8 2.2916667 0.3138825 21.67878 7.301033 1.6401545 2.943179 2.845268e-07

glass9 glass 9 2.8125000 0.3138825 21.67878 8.960359 2.1609878 3.464012 9.712344e-09

glass10 glass 10 2.8541667 0.3138825 21.67878 9.093105 2.2026545 3.505679 7.529370e-09

glass11 glass 11 3.0104167 0.3138825 21.67878 9.590902 2.3589045 3.661929 2.956211e-09

glass12 glass 12 2.8437500 0.3138825 21.67878 9.059918 2.1922378 3.495262 8.022476e-09

stagebottom stage bottom 0.9739583 0.2728556 12.74162 3.569500 0.3832721 1.564645 3.528167e-03

stagemiddle stage middle 1.2083333 0.2728556 12.74162 4.428471 0.6176471 1.799020 7.140623e-04

stagetop stage top 6.1927083 0.2728556 12.74162 22.695914 5.6020221 6.783395 1.101524e-11

wrapno wrap no 2.7534722 0.1820421 21.13430 15.125466 2.3750413 3.131903 8.228292e-13

wrapyes wrap yes 2.8298611 0.1820421 21.13430 15.545088 2.4514302 3.208292 4.830228e-13

…

#LSMEANS BY FIXED EFFECT OR INTERACTION FIXED EFFECT

1. lsdf.FoamHeight.glass <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight), which="glass", pairwise=TRUE))
2. lsdf.FoamHeight.stage <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight), which="stage", pairwise=TRUE))
3. lsdf.FoamHeight.wrap <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight), which="wrap", pairwise=TRUE))
4. lsdf.FoamHeight.glass.stage <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight), which="glass:stage", pairwise=TRUE))
5. lsdf.FoamHeight.glass.wrap <- as.data.frame(ls\_means(get\_model(mm.stepwmixedFoamHeight), which=“glass:wrap", pairwise=TRUE))

> ls\_means(gm.mm.stepwmixedFoamHeight, which = "stage", pairwise = TRUE)

Least Squares Means table:

Estimate Std. Error df t value lower upper Pr(>|t|)

stagebottom - stagemiddle -0.23437 0.35758 9.1 -0.6554 -1.04236 0.57361 0.5285

stagebottom - stagetop -5.21875 0.35758 9.1 -14.5945 -6.02674 -4.41076 1.322e-07 \*\*\*

stagemiddle - stagetop -4.98437 0.35758 9.1 -13.9390 -5.79236 -4.17639 1.973e-07 \*\*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Confidence level: 95%

Degrees of freedom method: Satterthwaite

> ls\_means(gm.mm.stepwmixedFoamHeight, which = "glass:stage", pairwise = TRUE)

Least Squares Means table:

Estimate Std. Error df t value lower upper Pr(>|t|)

glass1:stagebottom - glass2:stagebottom 1.2500e-01 4.5657e-01 26.5 0.2738 -8.1257e-01 1.0626e+00 0.7863720

glass1:stagebottom - glass3:stagebottom -1.8750e-01 4.5657e-01 26.5 -0.4107 -1.1251e+00 7.5007e-01 0.6846096

glass1:stagebottom - glass4:stagebottom 3.1250e-02 4.5657e-01 26.5 0.0684 -9.0632e-01 9.6882e-01 0.9459441

…

glass8:stagetop - glass9:stagetop -1.4375e+00 4.5657e-01 26.5 -3.1485 -2.3751e+00 -4.9993e-01 0.0040311 \*\*

glass8:stagetop - glass10:stagetop -1.4062e+00 4.5657e-01 26.5 -3.0801 -2.3438e+00 -4.6868e-01 0.0047741 \*\*

glass8:stagetop - glass11:stagetop -1.3750e+00 4.5657e-01 26.5 -3.0116 -2.3126e+00 -4.3743e-01 0.0056470 \*\*

glass8:stagetop - glass12:stagetop -1.4063e+00 4.5657e-01 26.5 -3.0801 -2.3438e+00 -4.6868e-01 0.0047741 \*\*

glass9:stagetop - glass10:stagetop 3.1250e-02 4.5657e-01 26.5 0.0684 -9.0632e-01 9.6882e-01 0.9459441

glass9:stagetop - glass11:stagetop 6.2500e-02 4.5657e-01 26.5 0.1369 -8.7507e-01 1.0001e+00 0.8921503

glass9:stagetop - glass12:stagetop 3.1250e-02 4.5657e-01 26.5 0.0684 -9.0632e-01 9.6882e-01 0.9459441

glass10:stagetop - glass11:stagetop 3.1250e-02 4.5657e-01 26.5 0.0684 -9.0632e-01 9.6882e-01 0.9459441

glass10:stagetop - glass12:stagetop -5.1348e-15 4.5657e-01 26.5 0.0000 -9.3757e-01 9.3757e-01 1.0000000

glass11:stagetop - glass12:stagetop -3.1250e-02 4.5657e-01 26.5 -0.0684 -9.6882e-01 9.0632e-01 0.9459441

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Confidence level: 95%

Degrees of freedom method: Satterthwaite

1H) Confirm best model found

> lmer(FoamHeight ~ glass + stage + wrap + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | stage:assessor) + (1 | stage:replicate)+glass:stage + glass:wrap, data=beerglassdata)

Type III Analysis of Variance Table with Satterthwaite's method

Sum Sq Mean Sq NumDF DenDF F value Pr(>F)

glass 48.61 4.419 11 12.93 2.9258 0.03496 \*

stage 410.59 205.295 2 9.07 135.9083 1.737e-07 \*\*\*

wrap 1.68 1.681 1 985.83 1.1125 0.29179

glass:stage 371.27 16.876 22 985.83 11.1721 < 2.2e-16 \*\*\*

glass:wrap 87.82 7.984 11 985.83 5.2853 3.708e-08 \*\*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

ANOVA-like table for random-effects: Single term deletions

Model:

FoamHeight ~ glass + stage + wrap + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | stage:assessor) + (1 | stage:replicate) + glass:stage + glass:wrap

npar logLik AIC LRT Df Pr(>Chisq)

<none> 54 -1931.8 3971.6

(1 | assessor:replicate) 53 -1939.6 3985.2 15.656 1 7.596e-05 \*\*\*

(1 | glass:assessor) 53 -1934.0 3974.0 4.460 1 0.034701 \*

(1 | glass:replicate) 53 -1941.2 3988.4 18.855 1 1.410e-05 \*\*\*

(1 | stage:assessor) 53 -1972.9 4051.8 82.211 1 < 2.2e-16 \*\*\*

(1 | stage:replicate) 53 -1935.3 3976.6 7.047 1 0.007939 \*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Backward reduced random-effect table:

Eliminated npar logLik AIC LRT Df Pr(>Chisq)

<none> 54 -1931.8 3971.6

(1 | assessor:replicate) 0 53 -1939.6 3985.2 15.656 1 7.596e-05 \*\*\*

(1 | glass:assessor) 0 53 -1934.0 3974.0 4.460 1 0.034701 \*

(1 | glass:replicate) 0 53 -1941.2 3988.4 18.855 1 1.410e-05 \*\*\*

(1 | stage:assessor) 0 53 -1972.9 4051.8 82.211 1 < 2.2e-16 \*\*\*

(1 | stage:replicate) 0 53 -1935.3 3976.6 7.047 1 0.007939 \*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Backward reduced fixed-effect table:

Degrees of freedom method: Satterthwaite

Eliminated Sum Sq Mean Sq NumDF DenDF F value Pr(>F)

glass:stage 0 371.27 16.8759 22 985.83 11.1721 < 2.2e-16 \*\*\*

glass:wrap 0 87.82 7.9836 11 985.83 5.2853 3.708e-08 \*\*\*

---

Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Model found:

FoamHeight ~ glass + stage + wrap + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | stage:assessor) + (1 | stage:replicate) + glass:stage + glass:wrap

[1] "BEST MIXED MODEL: FoamHeight"

Linear mixed model fit by REML ['lmerModLmerTest']

Formula: FoamHeight ~ glass + stage + wrap + (1 | assessor:replicate) + (1 | glass:assessor) + (1 | glass:replicate) + (1 | stage:assessor) + (1 | stage:replicate) + glass:stage + glass:wrap

Data: beerglassdata

REML criterion at convergence: 3863.581