

Completely randomized design

true

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One-way ANOVA & pairwise comparison post hoc tests in a completely randomized design.

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```
# (install &) load packages
pacman::p_load(
  broom,
  conflicted,
  desplot,
  emmeans,
  ggtext,
  multcomp,
  multcompView,
  tidyverse)

# handle function conflicts
conflict_prefer("filter", "dplyr")
conflict_prefer("select", "dplyr")
```

1 Data

This example is taken from “*Example 4.3*” of the course material “Quantitative Methods in Biosciences (3402-420)” by [Prof. Dr. Hans-Peter Piepho](#). It considers data published on p.52 of Mead (2002) from a yield trial with melons. The trial had 4 melon varieties (**variety**). Each variety was tested on six field plots. The allocation of treatments (varieties) to experimental units (plots) was completely at random. Thus, the experiment was laid out as a completely randomized design (CRD).

1.1 Import

```
# data is available online:
path <- "https://raw.githubusercontent.com/SchmidtPaul/dsfair_quarto/master/data/Mead1993."

dat <- read_csv(path) # use path from above
dat

# A tibble: 24 x 4
  variety yield    row    col
  <chr>   <dbl> <dbl> <dbl>
1 v1      25.1     4     2
2 v1      17.2     1     6
3 v1      26.4     4     1
4 v1      16.1     1     4
5 v1      22.2     1     2
6 v1      15.9     2     4
7 v2      40.2     4     4
8 v2      35.2     3     1
9 v2      32.0     4     6
10 v2      36.5     2     1
# ... with 14 more rows
```

1.2 Format

Before anything, the column **variety** should be encoded as a factor, since R by default encoded it as a character variable. There are multiple ways to do this - here are two:

```
dat <- dat %>%
  mutate(variety = as.factor(variety))
```

```
dat <- dat %>%
  mutate(across(variety, ~ as.factor(.x)))
```

1.3 Exploring

We make use of `dlookr::describe()`¹ to conveniently obtain a descriptive summary table:

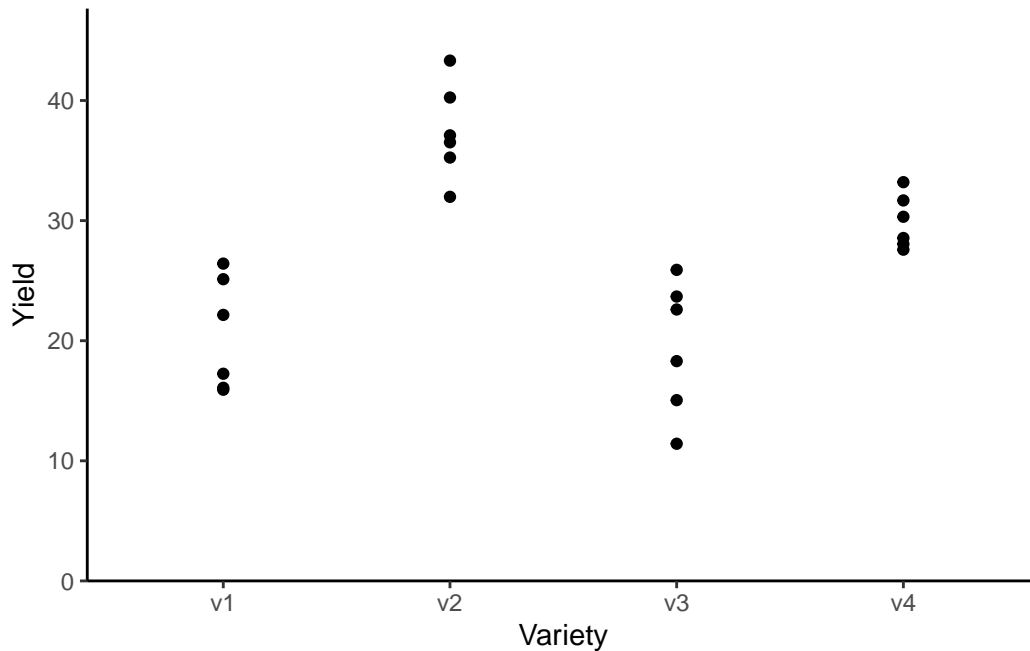
```
dat %>%
  group_by(variety) %>%
  dlookr::describe(yield) %>%
  select(variety:sd, p00, p100) %>%
  arrange(desc(mean))
```

```
# A tibble: 4 x 7
  variety      n    na mean    sd   p00  p100
  <fct>    <int> <int> <dbl> <dbl> <dbl> <dbl>
1 v2         6     0  37.4  3.95  32.0  43.3
2 v4         6     0  29.9  2.23  27.6  33.2
3 v1         6     0  20.5  4.69  15.9  26.4
4 v3         6     0  19.5  5.56  11.4  25.9
```

Additionally, we can decide to plot our data:

```
ggplot(data = dat) +
  aes(y = yield, x = variety) +
  geom_point() +
  scale_x_discrete(
    name = "Variety"
  ) +
  scale_y_continuous(
    name = "Yield",
    limits = c(0, NA),
    expand = expansion(mult = c(0, 0.1))
  ) +
  theme_classic()
```

¹As described in the {dlookr} section of the Summary Article “Useful things”.



Finally, since this is an experiment that was laid with a certain experimental design (= a completely randomized design; CRD) - it makes sense to also get a field plan. This can be done via `desplot()` from `{desplot}`:

```
desplot(
  data = dat,
  flip = TRUE, # row 1 on top, not on bottom
  form = variety ~ col + row, # fill color per variety
  text = variety, # variety names per plot
  cex = 1, # variety names: font size
  shorten = "no", # variety names: don't abbreviate
  main = "Field layout", # plot title
  show.key = FALSE # hide legend
)
```

Field layout

v3	v1	v4	v1	v4	v1
v2	v3	v4	v1	v2	v4
v2	v3	v4	v4	v3	v2
v1	v1	v3	v2	v3	v2

2 Model

Finally, we can decide to fit a linear model with `yield` as the response variable and (fixed) `variety` effects.

```
mod <- lm(yield ~ variety, data = dat)
```

Model assumptions should be checked at this point

TO DO

3 ANOVA

Based on our model, we can then conduct an ANOVA:

```
ANOVA <- anova(mod)
ANOVA
```

Analysis of Variance Table

```
Response: yield
      Df Sum Sq Mean Sq F value    Pr(>F)
variety  3 1291.48  430.49   23.418 9.439e-07 ***
Residuals 20  367.65   18.38
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Accordingly, the ANOVA's F-test found the variety effects to be statistically different ($p < .001^{***}$).

4 Mean comparison

Besides an ANOVA, one may also want to compare adjusted yield means between varieties via post hoc tests (t-test, Tukey test etc.).

```
mean_comp <- mod %>%
  emmeans(specs = ~ variety) %>% # adj. mean per variety
  cld(Letters = letters) # compact letter display (CLD)
```

```
mean_comp
```

variety	emmean	SE	df	lower.CL	upper.CL	.group
v3	19.5	1.75	20	15.8	23.1	a
v1	20.5	1.75	20	16.8	24.1	a
v4	29.9	1.75	20	26.2	33.5	b
v2	37.4	1.75	20	33.8	41.1	c

Confidence level used: 0.95

P value adjustment: tukey method for comparing a family of 4 estimates

significance level used: alpha = 0.05

NOTE: If two or more means share the same grouping letter,
then we cannot show them to be different.

But we also did not show them to be the same.

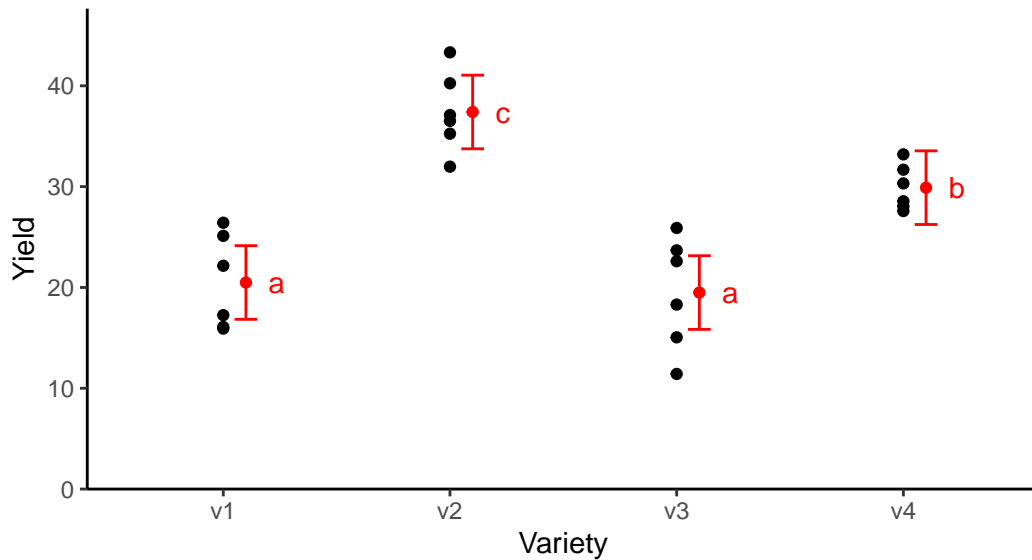
Note that if you would like to see the underlying individual contrasts/differences between adjusted means, simply add `details = TRUE` to the `cld()` statement. Furthermore, check out the Summary Article “Compact Letter Display”.

Finally, we can create a plot that displays both the raw data and the results, *i.e.* the comparisons of the adjusted means that are based on the linear model.

```
my_caption <- "Black dots represent raw data. Red dots and error bars represent adjusted m

ggplot() +
  aes(x = variety) +
  # black dots representing the raw data
  geom_point(
    data = dat,
    aes(y = yield)
  ) +
  # red dots representing the adjusted means
  geom_point(
    data = mean_comp,
    aes(y = emmean),
    color = "red",
    position = position_nudge(x = 0.1)
  ) +
  # red error bars representing the confidence limits of the adjusted means
  geom_errorbar(
    data = mean_comp,
    aes(ymin = lower.CL, ymax = upper.CL),
    color = "red",
    width = 0.1,
    position = position_nudge(x = 0.1)
  ) +
  # red letters
  geom_text(
    data = mean_comp,
    aes(y = emmean, label = str_trim(.group)),
    color = "red",
    position = position_nudge(x = 0.2),
    hjust = 0
  ) +
  scale_x_discrete(
    name = "Variety"
  ) +
  scale_y_continuous(
    name = "Yield",
    limits = c(0, NA),
    expand = expansion(mult = c(0, 0.1))
  )
```

```
) +
theme_classic() +
labs(caption = my_caption) +
theme(plot.caption = element_textbox_simple(margin = margin(t = 5)),
      plot.caption.position = "plot")
```



Black dots represent raw data. Red dots and error bars represent adjusted means with 95% confidence limits per variety. Means followed by a common letter are not significantly different according to the Tukey-test.

Mead, Roger, Robert N. Curnow, and Anne M. Hasted. 2002. *Statistical Methods in Agriculture and Experimental Biology*. 3rd ed. CRC Press.