

One-way completely randomized design

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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(
  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, Curnow, and Hasted (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
# i 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 Explore

We make use of `dlookr::describe()` to conveniently obtain descriptive summary tables. Here, we get can a summary per variety.

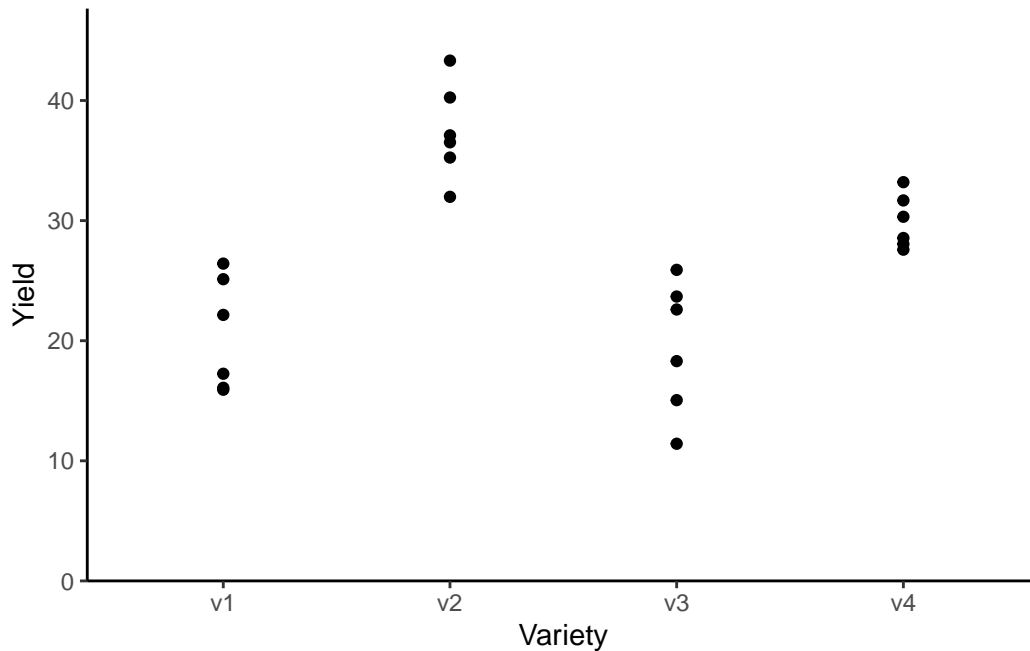
```
dat %>%
  group_by(variety) %>%
  dlookr::describe(yield) %>%
  select(2:sd, p00, p100) %>%
  arrange(desc(mean))
```

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()
```



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)
```

It would be at this moment (i.e. after fitting the model and before running the ANOVA), that you should check whether the model assumptions are met. Find out more in the [summary article “Model Diagnostics”](#)

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 symbol,
      then we cannot show them to be different.
```

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

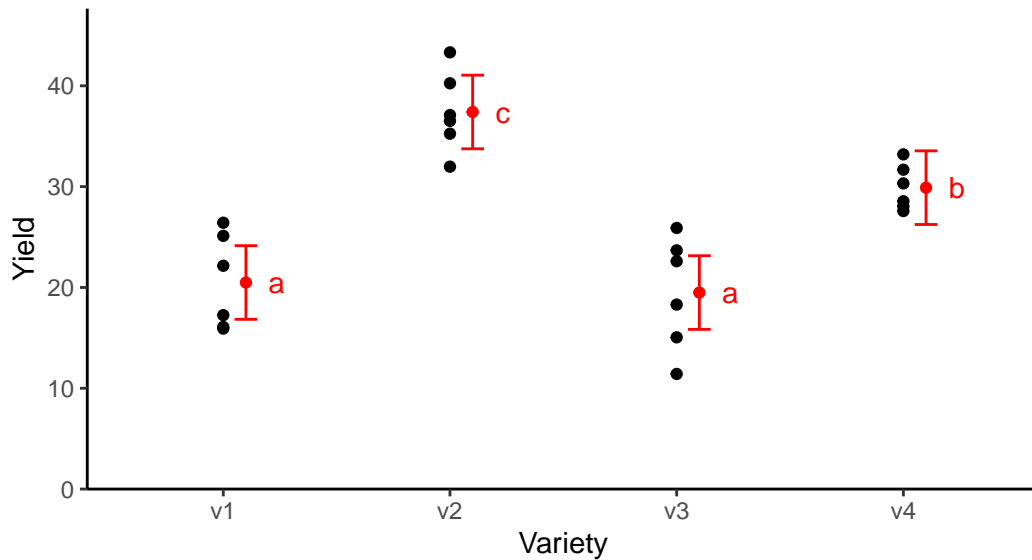
Note that if you would like to see the underlying individual contrasts/differences between adjusted means, simply add `details = TRUE` to the `cld()` statement. Furthermore, check out the [Summary Article “Compact Letter Display”](#).

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.