Quantifying and Comparing the Effects of Intra-/Inter-specific Competition between *Triticum aestivum* (wheat) and *Raphanus sativus* (radish) on Wheat Biomass

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6 April 2020

INTRODUCTION

Ecological competition affects species interactions, birth and death rates of a population, and plays a critical role in community dynamics. Plants compete in below-ground and above-ground environments for resources such as nutrients, sunlight, pollinators, bacterial communities, and more (Casper and Jackson, 1997). Intra-specific competition among plants has shown to affect population dynamics by decreasing individual plant production including metrics such as leaf number and mass (Ungar, 1992). Inter-specific competition can eliminate or give rise to a species according to Gause's Law, in which two competing organisms that use the same resources cannot coexist, and greater relatedness often leads to stronger competitive interactions (Violle *et al*., 2011). In the field of agriculture, plant competition dynamics are the underlying principles in crop rotations, intercropping, biological pest control, and other adaptive strategies (Wezel et al. 2014). Previous studies analyzing plant competition have given rise to new agricultural strategies, such as in crop-weed competition and applying group selection in crops to reduce intra-specific competition (Weiner, 2010). Understanding competition dynamics and whether intra- or inter-specific competition is stronger, can shape future agricultural techniques. In this experiment, the effects of intra- and inter-specific competition between *Triticum aestivum* (wheat) and *Raphanus sativus* (radish) were analyzed. Radish and wheat sprouts were planted at varying densities, and after five weeks, wheat bio-masses were compared. Because of the differences in resource-acquisition strategies between wheat and radish, inter-specific competition will have a larger effect on wheat biomass than intra-specific competition.

METHODS

To test for intra- and inter-specific competition, multiple experimental groups were used. The control group consisted of two wheat seedlings. Experimental groups to simulate intra-specific competition included groups of four wheat seedlings and six wheat seedlings. Experimental groups to simulate inter-specific competition included one wheat/one radish, two wheat/two radish, three wheat/three radish, two wheat/four radish, and four wheat/two radish seedlings. Each experimental group had four replicates, with a total of 32 experimental groups.

Each experimental group used germinated wheat and radish seeds that were planted at one-inch depth in 200mL of loosely packed normal soil. Each experimental group was randomly placed in a eight-by-four grid and received consistent watering and a natural light cycle for five weeks. The seedlings were then uprooted, massed with the root and stem, and recorded. Statistical significance was determined using an ANOVA test and Tukey HSD test with a critical value of 0.05 in R Studio (R Core Team, 2020).

RESULTS

The results represent biomasses of wheat seedlings that were grown with varying levels of intra- or inter-specific competition with other wheat and radish seedlings. The biomasses of wheat seedlings grown in groups of two, four, and six represent intra-specific competition (figure 1). Four replicates were used for each experimental group. The median biomass of wheat seedlings decreased as they were grown with more wheat seedlings. The data showed a statistical difference between the mean biomass of wheat plants when facing intra-specific competition (one-side ANOVA with Tukey HSD, F-value = 6.892, Probability = 0.0153, $\alpha = 0.05$, df = 2, n = 12).

The biomasses of wheat seedlings grown in groups of four or six, mixed with some radish seedlings, represent inter-specific competition (figure 2). Four replicates were used for all experimental groups. The median biomass of wheat seedlings increase when grown with radish seedlings (figure 2). The data shows a statistically significant difference between mean biomasss of wheat plants when facing inter- specific competition (one-sided ANOVA with Tukey HSD, F-statistic = 6.536, p = 0.00145, α = 0.05, df = 5, n = 24).

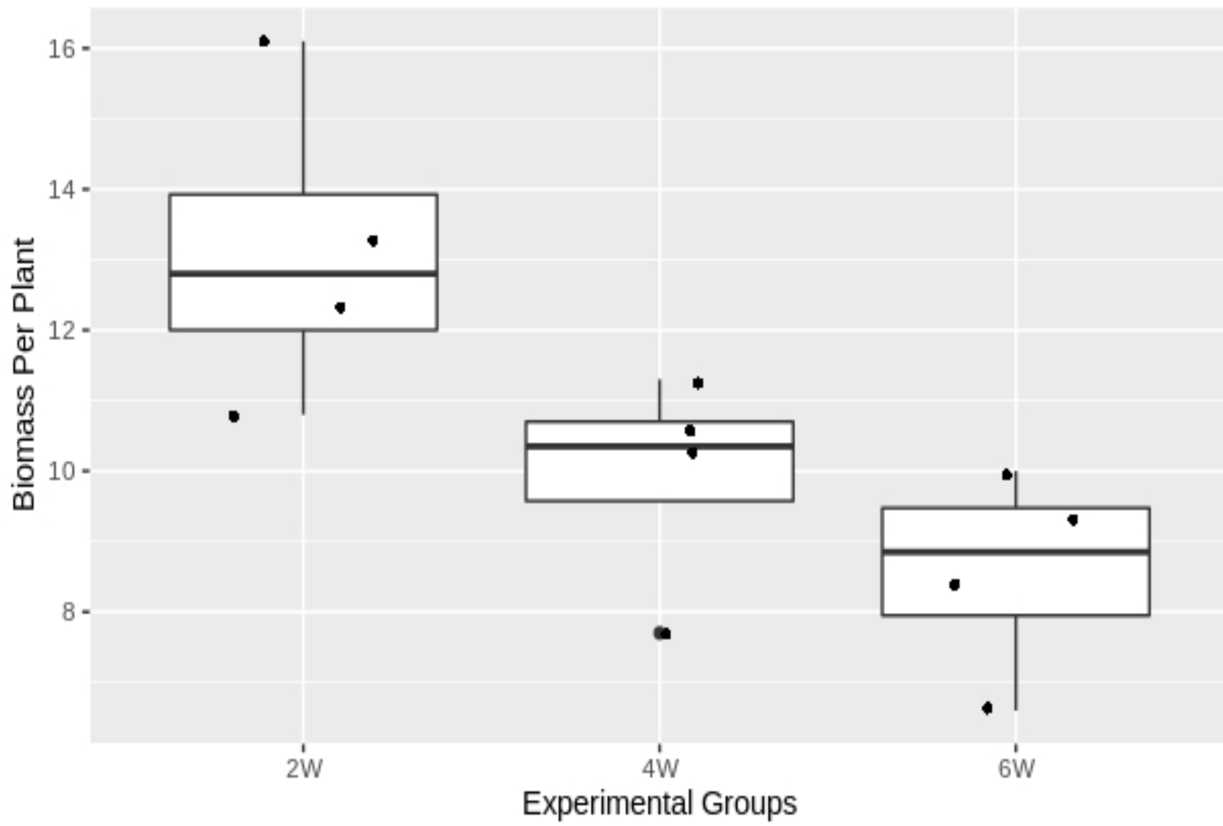

Fig 1. *Biomass of wheat seedlings in intra-specific competition.* Wheat seedlings were grown in groups of two, four or six total seedlings with four replicates for each group, shown along the x-axis. The biomass for each seedling was measured and plotted as a box-whisker plot along the y-axis. There is a statistically significant change in mean biomass between groups (one-way ANOVA with Tukey HSD, F-value = 6.892, Probability = 0.0153, α = 0.05, df = 2, n = 12). The median biomass decreases as the number of wheat seedlings increases.

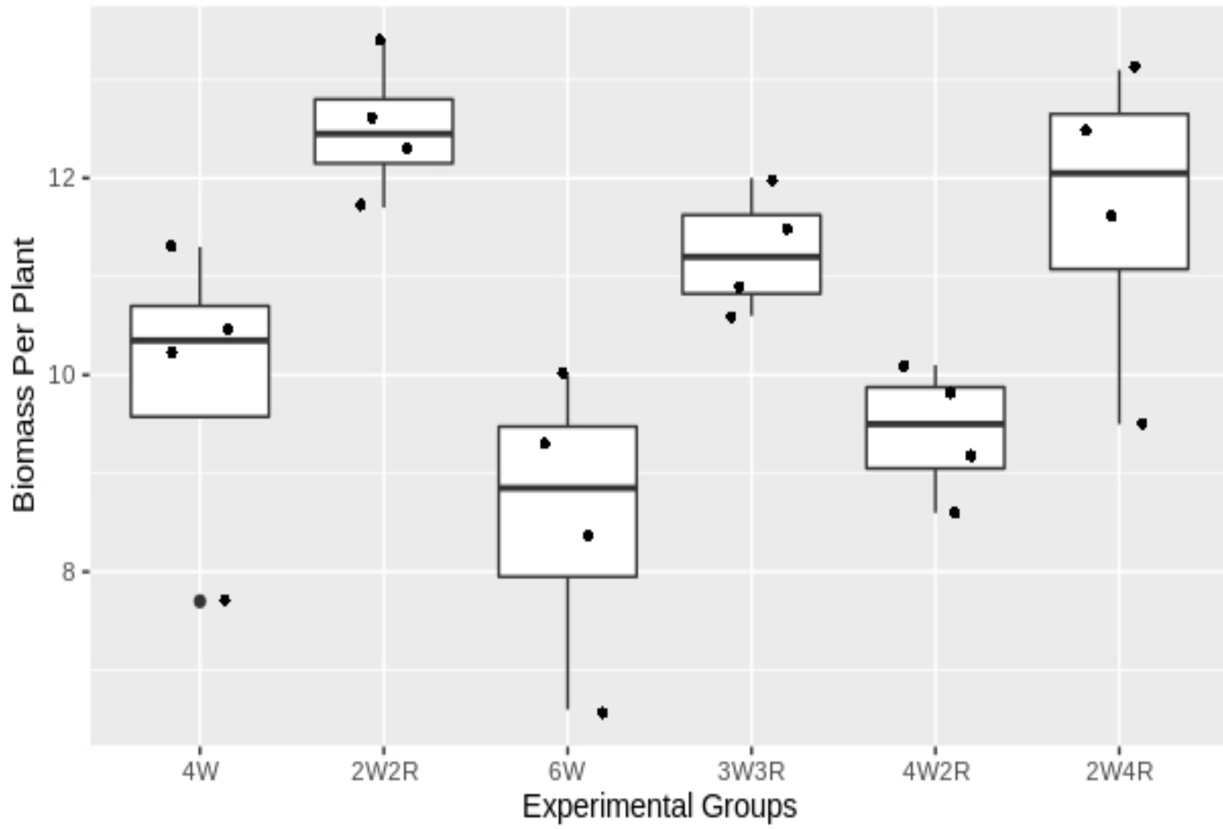

Fig 2. *Biomass of wheat seedlings in inter-specific competition.* Wheat seedlings were grown with radish seedlings and compared to wheat seedlings grown with only other wheat seedlings. Experimental groups had four replicates each. The biomass for each seedling was measured and plotted as a box-whisker plot along the y-axis. There was a statistical difference between mean biomass across all experimental groups (one-sided ANOVA with Tukey HSD, F-statistic = 6.536, $p = 0.00145$, $\alpha = 0.05$, df = 5, n = 24). The median biomass of wheat seedlings increases when grown with radish seedlings.

DISCUSSION

The experiment supports the hypothesis. The effects of inter-specific competition had a greater effect on wheat biomass than intra-specific competition, even though both competition types created statistically significant differences in biomass.

The results showed a statistically significant decrease in mean wheat biomass in intra-specific competition. Wheat seedling biomass decreased as the number of wheat seedlings grown in a group increased across all three experimental groups (figure 1). However, when analyzing significance between pairs of experimental groups, only the two-wheat and six-wheat groups showed statistically significant results, with an adjusted p-value of 0.014 from the Tukey HSD test (figure 1). The differences in biomass between the two-wheat and four-wheat groups and the four-wheat and six-wheat groups were not statistically significant, with adjusted p-values of 0.074 and 0.55 respectively (figure 1). This suggests that the effects of intra-specific competition have only a mild effect on wheat seedlings since their biomass doesn't change greatly unless a large number of additional seedlings are grown alongside them. This trend has been found in other studies, in which plant biomass in maize crops decreased in monocultures, and the productive fate of plants is influenced in its early life stage (Maddonni and Otegui, 2004).

The results showed a statistically significant difference in wheat biomass in inter-specific competition. Wheat seedling biomass increased when grown with radish seedlings across all experimental groups, although statistical significance between pairs of experimental groups vary (figure 2). The only pairs of experimental groups with statistically significant differences were the six-wheat and two-wheat/four-radish as well as the six-wheat and three-wheat/three-radish groups, both with adjusted p-values of 0.017 (figure 2). The increase in biomass found in inter-specific competition suggest that wheat seedlings out-compete radish seedlings. This could be due to a number of strategies in which plants out-compete one another, including blocking sunlight, absorbing nutrients quicker, or changing soil bacteria communities (Hortal *et al.*, 2017). Additionally, the biomass of wheat seedlings from the four-wheat/two-radish group showed a lower median biomass than the three-wheat/three-radish and two-wheat/four-radish groups. The four-wheat/two-radish group had less inter-specific and more intra-specific competition, which is consistent with both trends found in intra- and inter-specific competition.

The differences in biomass from the inter-specific competition groups were statistically greater than the differences in biomass from the intra-specific competition groups, with p values of 0.00145 and 0.0153 respectively (Figures 1 and 2). This is because intra-specific competition predictably reduces biomass of wheat seedlings. Inter-specific competition however can have a large effect on the organism depending on the competitive superiority of the organism. A previous study shows the growth of potato biomass amplified by the presence of an inferior maize crop, which provides further support of the large, positive effect of inter-specific competition on the superior species (Mushagalusa *et al.*, 2008). The wheat seedlings showed evidence of competitive superiority and a larger change in biomass much more than the wheat seedlings when competing against each other.

The experiment assumes that the soil had a homogeneous distribution of nutrients, however normal soil rather than sterilized soil was used. This suggests that nutrients and soil bacteria were spread heterogeneously, favoring some seedlings over others. Although future studies should consider sterilized soil, these results still have limited bias because the seedlings were planted randomly, and studies have shown that soil nutrient heterogeneity does not affect competition between plants at least in intra-specific competition (Zhou *et al.*, 2012).

Although both intra- and inter-specific competition showed significant effects on wheat biomass, the experiment showed that inter-specific competition caused greater changes in biomass. Wheat seedlings showed a small decrease in biomass in intra-specific competition but showed a large increase in biomass in inter-specific competition. Investigating the competitive relationship between plants and crops can help create successful agroecological practices to minimize crop competition and maximize production (Wezel *et al.*, 2014). Understanding plant competition dynamics will help guide future agricultural strategies as society faces growing food demands

SUPPLEMENTAL DATA

```
#plant competition data, Ecology Lab
# author Benjamin Ahn 03_31_2020
# version 1.0

#import data and packages
library(dplyr);
library(ggplot2);
experimental_data <- read.csv(file.choose(new = FALSE));

#split into groups
intraspecific <- experimental_data[1:12,];
interspecific <- experimental_data[c(5:13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41,
43),];

intraspecific.lm <- lm(intraspecific$BiomassPerPlant ~ intraspecific$Treatment);
interspecific.lm <- lm(interspecific$BiomassPerPlant ~ interspecific$Treatment);

#statistical tests
intraspecific.aov <- aov(intraspecific.lm);
TukeyHSD(intraspecific.aov);
interspecific.aov <- aov(interspecific.lm);
TukeyHSD(interspecific.aov);

#boxplots
treatment_biomass <- select(experimental_data, "Treatment", "BiomassPerPlant");
treatment_biomass$Treatment <- factor(treatment_biomass$Treatment, levels = c("2W", "4W",
"2W2R", "6W", "3W3R", "4W2R", "2W4R"));
treatment_biomass$BiomassPerPlant <-
as.numeric(as.character(treatment_biomass$BiomassPerPlant));
plotmain <- ggplot(treatment_biomass, aes(x = Treatment, y = BiomassPerPlant)) +
geom_boxplot() +
  labs(x="Experimental Groups",
       y = "Biomass Per Plant");
plotmain_points <- plotmain +  geom_jitter(shape=16, position=position_jitter(0.2));

treatment_biomass_intra <- select(intraspecific, "Treatment", "BiomassPerPlant");
treatment_biomass_intra$BiomassPerPlant <-
as.numeric(as.character(treatment_biomass_intra$BiomassPerPlant));
plot_intra <- ggplot(treatment_biomass_intra, aes(x = Treatment, y = BiomassPerPlant)) +
geom_boxplot() +
  labs(x = "Experimental Groups",
       y = "Biomass Per Plant");
plot_intra_points <- plot_intra + geom_jitter(shape=16, position=position_jitter(0.2));

treatment_biomass_inter <- select(interspecific, "Treatment", "BiomassPerPlant");
treatment_biomass_inter$Treatment <- factor(treatment_biomass_inter$Treatment, levels =
c("4W", "2W2R", "6W", "3W3R", "4W2R", "2W4R"));
```

```
treatment_biomass_inter$BiomassPerPlant <-
as.numeric(as.character(treatment_biomass_inter$BiomassPerPlant));
plot_inter <- ggplot(treatment_biomass_inter, aes(x = Treatment, y = BiomassPerPlant)) +
geom_boxplot() +
  labs(x = "Experimental Groups",
       y = "Biomass Per Plant");
plot_inter_points <- plot_inter + geom_jitter(shape=16, position=position_jitter(0.2));
```

end

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