PLS100CL : Lab Final
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Drought responses in two varieties of wheat

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Executive Summary

In the comparison between two varieties of wheat, the variety Patwin515HP displayed more grain productivity in drought conditions simulated by our dry treatments in the characteristics of yield per head, heads per tiller, total heads per plant, and total tillers per plant and generally showed an advantage in these characteristics over the variety Central Red in normal irrigation conditions. However, the Central Red variety demonstrated physiological responses in dry treatments characteristic of drought resistance such as smaller losses in yield per head and tiller and head growth, more root growth, maintenance of internal water pressure and water content, reduced transpiration, and higher viable leaf area in dry conditions.

Introduction and Background

This investigation is aimed at observing the differences in response to environment between two varieties of wheat. The primary objective is to determine possible advantages of one variety over the other in drought conditions. Drought tolerance is useful for crop management in the event of unpredictable or previously inhospitable climate conditions and nonnative cropping systems. This could enable crops to be biological and commercially viable in novel crop systems by increasing the profit margins of these systems. Water is a necessary reactant in photosynthesis and, by extension, biomass production so we expected to observe at least some signs of water deprivation as decreases in biomass in the form of heads, tillers, shoots, roots, and leaf area in this experiment. A successfully drought tolerant plant in low water conditions might exhibit characteristics including, but not limited to, increased water uptake, retaining internal water levels, and, ultimately, maintaining production of yield despite low water availability. The decidedly superior variety may also provide the benefit of higher yields during normal irrigation. It is not always entirely clear that any given statistic represents a plant's heritable defensive response and acclimation to low water conditions or is a sign of physiological damage inflicted onto the plant by the hostile drought conditions. Such judgements about the nature of the observations and their utility in developing breeds for success in drought conditions will have to be made with reference to the web of other statistical trends and biological processes affected in the experiment, while keeping a relational connection to the production of grain that will ultimately benefit agricultural endeavors.

Until this point measurements had been taken from subjects at weeks 0 (seed), 0.14, 1, 2, 5, and 9. Weight tracking from weeks 0 thru 2 confirmed the effectiveness of our controls on the growth environment. The irrigation lines that supplied water to each treatment bed were supplying water within the expected range of variability. Differences in fresh weight at week 0 and 0.14 revealed that Red had a larger seed based on significant differences in fresh weight. Other genotypic differences in fresh weight in the following weeks were not significant until week 5, when treatments were introduced. Week 1 saw the formation of early tillers and leaf blades, with an increase in biomass production. With the use of a pressure bomb and LiCor devices, stem water potential trials in the greenhouse and the field revealed that Central Red maintained internal water content, reduced respiration, and retained chlorophyll amounts in dry conditions in comparison to Patwin in dry conditions.

Methods and Materials

The wheat varieties of Patwin and Central Red were subject to dry treatment, which consisted of low water irrigation practices simulating drought conditions, and wet treatment, which simulated normal irrigation management. These crops were raised and monitored in the Bowley greenhouse for 13 weeks. Dry and wet treatments began before the onset of tillering, at week 5. Several physiological characteristics were tracked and recorded during this time. This data was compiled as ANOVA tables and Type III Sum of Squares tests were deployed for determining significance. The accepted threshold for significance was a Pr>F value of .05 or less, where Pr>F represents the probability that differences observed in the data was attributed to random chance. When the Pr>F value was very close to .05, it was indicated as such in the analysis. The null hypothesis in these tests generally stated that if Pr>F was greater than .05 there was no significant difference in the data along the given parameter. If Pr>F was less than .05 we reject the null and the alternative hypothesis stated that there was evidence that a significant difference was present in the data.

Results

While dry treatments reduced yields in a significant way for Patwin and Central Red subjects, statistical analysis of our measurements of total yield failed to provide evidence that either variety responded differently to treatments. These facts can be seen in Table 1, as no significant variety differences or interaction was revealed. This might be because yield is a summative statistic that encompasses several variables in the botany of wheat structure. To find nuances in response, we'll have to investigate the yield components. In this study, yield was broken down into yield per head, heads per tiller, and number of tillers per plant, with the alternative deconstruction of yield per head and number of heads per plant.

Considering our first component in yield, the Patwin variety appears to have a higher average yield per head in dry conditions. This is demonstrated in the means included in Table 2. Based on means alone, the standard deviations for the Patwin variety was too great to make a definitive claim about Patwin superiority but since yield per head was similar in wet conditions for both varieties, we see that Red suffered greater loss in yield per head in dry conditions and this is verified by a significant variety x treatment interaction in Table 1.

Continuing to the second yield component, Patwin maintains head per tiller rate in dry conditions better than Red as evidenced by a significant interaction in Table 1. The means in Table 2 describe how the effects of wet conditions were observed similar between the two varieties and dry treatment produced significant effects for both but more so for Red. The statistic "heads per tiller" coupled with "yield per head" alone could be indicative of Pat's higher grain production in drought conditions if the two varieties produced similar amount of tillers in dry conditions.

Pr>F	Yield	Yield per Head	Head per Tiller
Variety	0.263	0.771	0.003
Treatment	<.0001	<.0001	0.001
Variety x Treatment	0.626	0.015	0.008

Table 1. The table above presents the Pr>F statistic extracted from several ANOVA tables.The classes of comparison are found on the left most column and the standards of measurement corresponding to the data are listed in a row across the top.

Level of Variety	Level of treatment	N	Yield		YieldPerHead		HeadsPerTiller	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pat	**D**	8	1.16125000	0.74518334	0.15982887	0.12192311	0.96834936	0.23069958
Pat	**W**	8	7.82750000	1.95668634	0.45558888	0.17218040	1.01438049	0.18494833
Red	**D**	8	0.36125000	0.47260486	0.05681548	0.06672749	0.62400794	0.12840230
Red	**W**	8	7.51000000	1.75284259	0.58503359	0.12620596	0.99367560	0.04725728

Table 2. The table above presents the means from the raw data as it corresponds to each class. N signifies the number of test subjects in each class. The classes are indicated in the two leftmost column and the standards measurement in the row across the top.

According to the visual graphic in Figure 1, Patwin clearly had the highest tiller count in wet conditions by week 13, a possible sign of genotypic advantage for the variety. In dry conditions, the number of tillers were not significantly different between the two varieties. Given its high tiller counts in high irrigation conditions, the effects of dry treatments appeared to be the most severe on Patwin. This is confirmed by a significant interaction revealed in Table 3.

Patwin had considerably higher head count per tiller in wet conditions while head counts were similar for both varieties in dry conditions. This is evidenced in Figure 2 and a significant difference in variety in Table 3. Similar to what we observed in number of tillers, this indicated that dry conditions produced a more severe decrease in head count for Patwin than for Central Red and is supported by a significant interaction in Table 3.

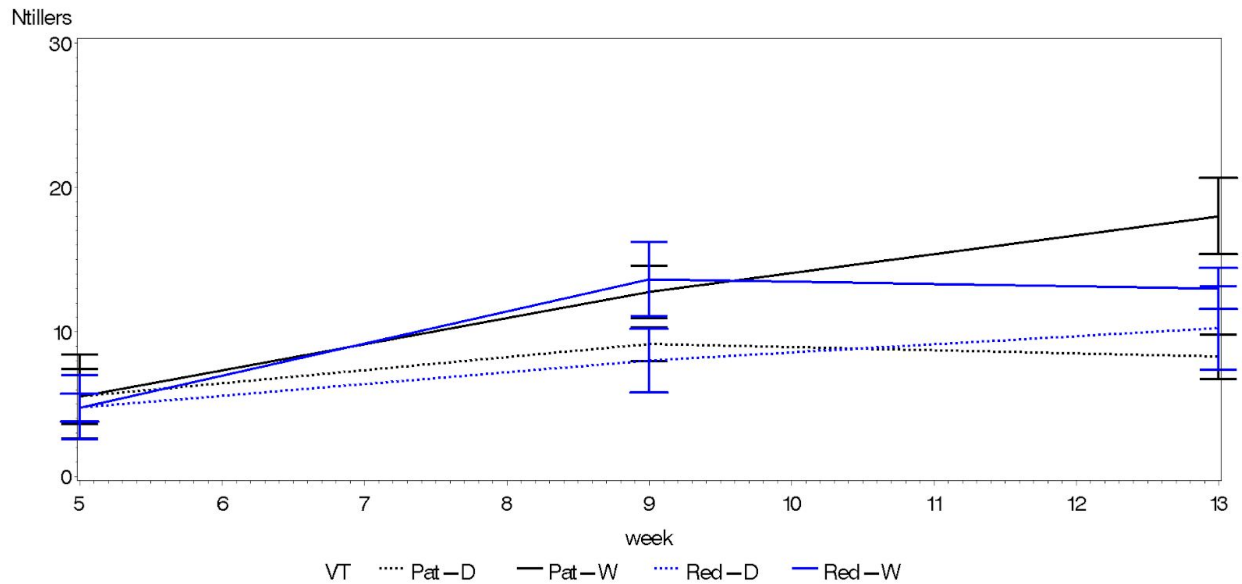

Figure 1. The graph above displays the mean number of tiller per plant for each development period with linear projections for each genotypic variety and treatment. NTillers is the mean number of tillers and can be found on the left-hand side while time in increments by week is enumerated along the bottom

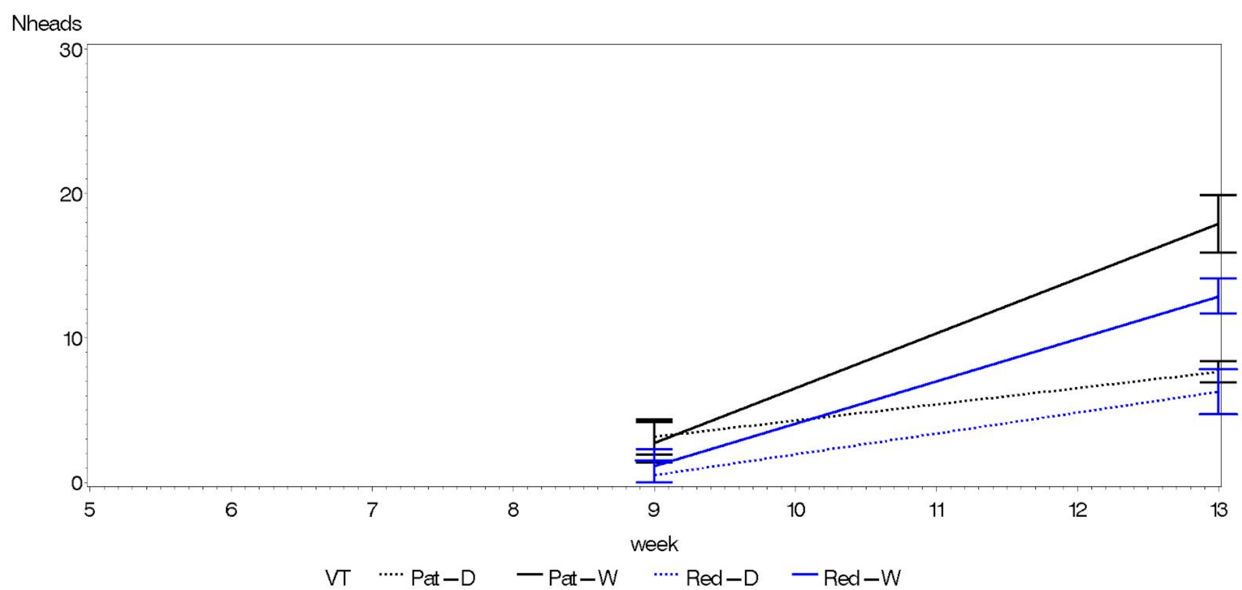

Figure 2. The graph above displays the mean number of heads per plant for each development period with linear projections for each genotypic variety and treatment. Nheads is the mean number of heads and can be found on the left-hand side while time in increments by week is enumerated along the bottom

Week 13		
Pr>F	Number of Tillers per Plant	Number of Heads per Plant

Variety	0.188	0.0001
Treatment	<.0001	<.0001
Variety x Treatment	0.003	0.001

Table 3. The table above presents the Pr>F statistic extracted from two ANOVA tables.The classes of comparison are found on the left most column and the standards of measurement corresponding to the data are listed in a row across the top.

As we expected, dry treatment produced effects in both varieties along the lines of decreased total dry weight. This is demonstrated in Figure 3. An increase in dry weight for wet treatments was observed in week 9 and continued until week 13 where as dry treatment dry weight stagnated or decreased after week 9. The low availability of water was likely to have limited photosynthetic activity, a potential cause of this trend. A significant difference in dry weight for variety was observed in Table 4 and seems to describe Red's slightly higher means in both wet and dry conditions in Table 5. For more detailed information, we have broken down dry weight measurements into roots and shoots.

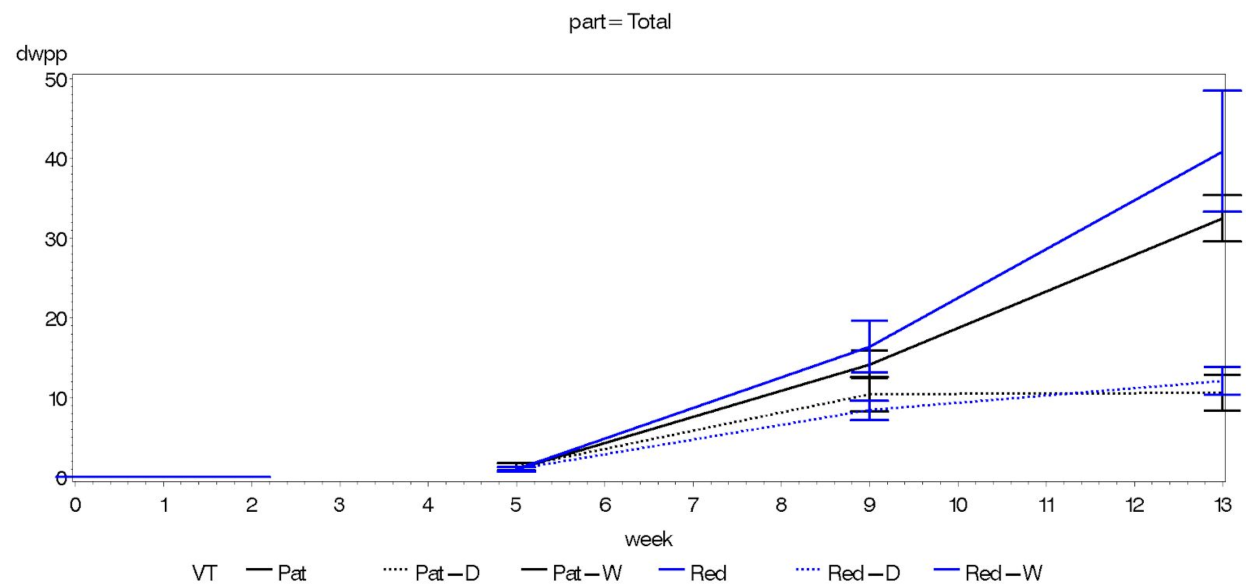

Figure 3. The graph above displays the dry weight means for each development period with linear projections for each genotypic variety and treatment. The dry weight per plant (DWPP) can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Week 13		
Pr>F	Dry Weight per Plant	Fresh Weight per Plant
Variety	0.029	0.012
Treatment	<.0001	<.0001
Variety x Treatment	0.121	0.046

Table 4. The table above presents the Pr>F statistic extracted from two ANOVA tables.The classes of comparison are found on the left most column and the standards of measurement corresponding to the data are listed in a row across the top.

Level of Variety	Level of treatment	N	dwpp		FWPP		pctH2O	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pat	D	4	1.32600000	0.47379109	10.0637500	2.35516233	86.1064889	7.08751745
Pat	W	4	1.02900000	0.25686962	8.9027500	2.15799681	88.3184728	2.33497394
Red	D	4	1.01400000	0.27439995	9.1325000	2.85026753	88.7233659	1.33060146
Red	W	4	1.05950000	0.22378785	10.0025000	2.12910584	89.4058489	0.66678428

Table 5. The table above presents the means from the raw data as it corresponds to each class. N signifies the number of test subjects in each class. The classes are indicated in the two leftmost column and the standards measurement in the row across the top.

The visualization of means in Figure 4 present that Red had greater root mass in wet conditions. In dry conditions, root mass was similar, signalling a more profound effect on Central Red than Patwin as supported by significant interaction in Table 6.

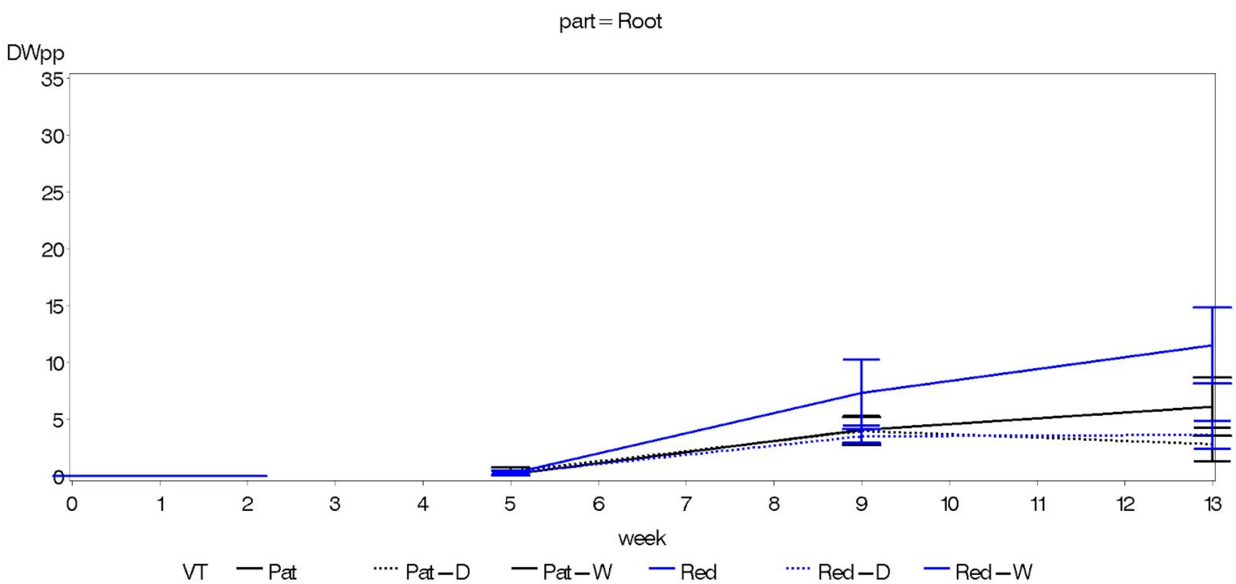

Figure 4. The graph above displays the root dry weight means for each development period with linear projections for each genotypic variety and treatment. The root dry weight per plant (DWPP) can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Week 13	
Pr>F	Root Dry Weight
Variety	0.012

Treatment	<.0001
Variety x Treatment	0.059

Table 6. The table above presents the Pr>F statistic extracted from the Root Dry Weight ANOVA table.The classes of comparison are found on the left most column.

Treatment produced significant effects on both varieties like those observed in total dry weight. No detectable differences in variety were found in the statistical analysis in Table 7. This appears to indicate that Red’s higher total dry weight means in Table 5 could be accounted for by greater root mass. This advantage in root growth could translate to more water uptake by Central Red, which warrants an inspection of fresh weight and percent H_2O.

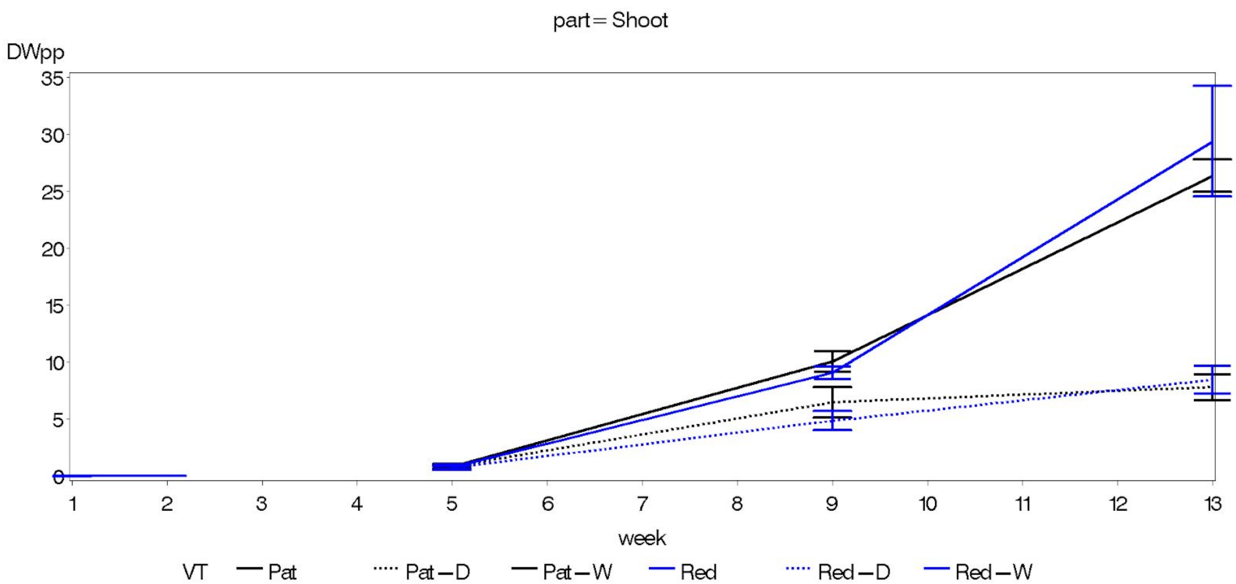

Figure 5. The graph above displays the shoot dry weight means for each development period with linear projections for each genotypic variety and treatment. The shoot dry weight per plant (DWPP) can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Week 13	
Pr>F	Shoot Dry Weight
Variety	0.176
Treatment	<.0001
Variety x Treatment	0.385

Table 7. The table above presents the Pr>F statistic extracted from the Shoot Dry Weight ANOVA table.The classes of comparison are found on the left most column.

At week 9, Central Red displayed an almost significant lead over Patwin in total fresh weight at a Pr>F value of 0.062 in variety difference. This is clear from Figure 6 and Table 8.

Differences in treatments grew pronounced at this stage as well. At week 13, Red went on to increase its lead over Patwin in wet conditions while fresh weights in dry conditions remained similar and stagnated, resembling the outcome of total dry weight measurements. Because of this, Red appears to have lost greater weight as a result of dry treatments than Patwin, which is presented as significant interaction in Table 4. In week 13, Red had a higher mean for fresh weight but a very large standard deviation as we see in Table 5. Since percent H_2O, which is explored below in Figure 7, was similar across varieties and treatments, this difference is likely to describe Red's greater biomass. This is supported by observations of significantly greater dry root mass in Red for wet and dry conditions in Figure 4. Dry treatment appears to have affected Red more than Patwin, as demonstrated by a significance value of .046 in interaction, although Red does have a slightly higher mean fresh weight than Patwin in dry conditions.

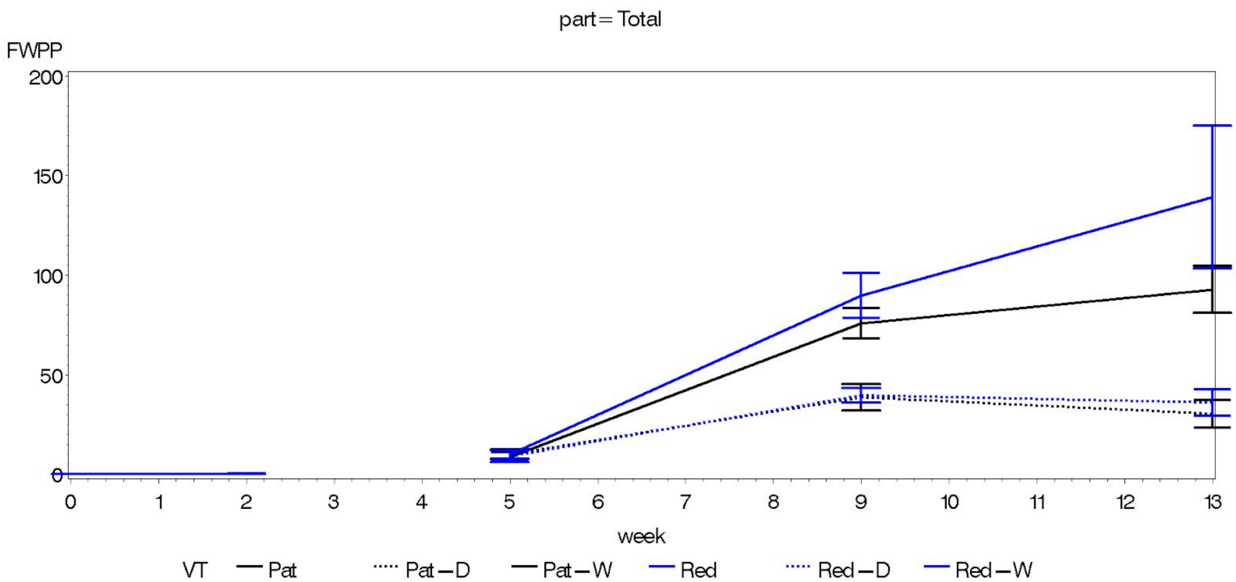

Figure 6. The graph above displays the fresh weight means for each development period with linear projections for each genotypic variety and treatment. The fresh weight per plant (FWPP) can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Week 9	
Pr>F	Fresh Weight per Plant
Variety	0.062
Treatment	<.0001
Variety x Treatment	0.108

Table 8. The table above presents the Pr>F statistic extracted from the Total Fresh Weight ANOVA table for week 9.The classes of comparison are found on the left most column.

Week 13	
Pr>F	Mean Fresh Weight per Plant

Variety	0.012
Treatment	<.0001
Variety x Treatment	0.046

Table 8.5. The table above presents the Pr>F statistic extracted from the Total Fresh Weight ANOVA table for week 13.The classes of comparison are found on the left most column.

Percent H2O showed significant differences in week 9, where both varieties had very similar means in Wet conditions but Red maintained water content better in dry conditions. This differential effect in irrigation treatment was significant in that 5.7% of the difference could be accounted for by random chance, displayed below in Table 9. Furthermore, the means in Table 10 indicate that a significant variety difference when varieties were so similar in one treatment underscores the significance of their differences in the other treatment, which is again supported by our stats for significant interaction. By week 13 however, these significant differences disappeared and means lined up again, across treatments and varieties. This was determined from Table 10 and Figure 7. This may have something to do with the allocation of water resources prior to head formation since this was a major event in the period between week 9 and 13 as we saw Figure 2 presenting number of heads per plant. Pat's high head count might have been initially more demanding on water resources where water is required for photosynthesis and carbon production and, in combination with comparatively less root mass resulting less uptake and less cellular respiration, the total water content in Patwin plants was less than that of Red. After head formation was underway, water content in Patwin might have reached a balance resembling Red's levels.

Week 9	
Pr>F	Percent H2O
Variety	0.017
Treatment	0.0002
Variety x Treatment	0.057

Table 9. The table above presents the Pr>F statistic extracted from the Percent H2O ANOVA table for week 9.The classes of comparison are found on the left most column.

Week 9		Mean Percent H2O	Standard Deviation
Patwin	Dry	72.8851899	4.86586036
Patwin	Wet	81.1386118	3.29307117
Central Red	Dry	78.7957673	3.64181766
Central Red	Wet	81.8597142	2.66983958

Table 10. *The table above presents the Percent H2O means and standard deviations from the raw data as it corresponds to each class. The classes are indicated in the two leftmost column and the standards measurement in the row across the top.*

Week 13	
Pr>F	Percent H2O
Variety	0.167
Treatment	0.331
Variety x Treatment	0.793

Table 11. The table above presents the Pr>F statistic extracted from the Percent H2O ANOVA table for week 13. The classes of comparison are found on the left most column.

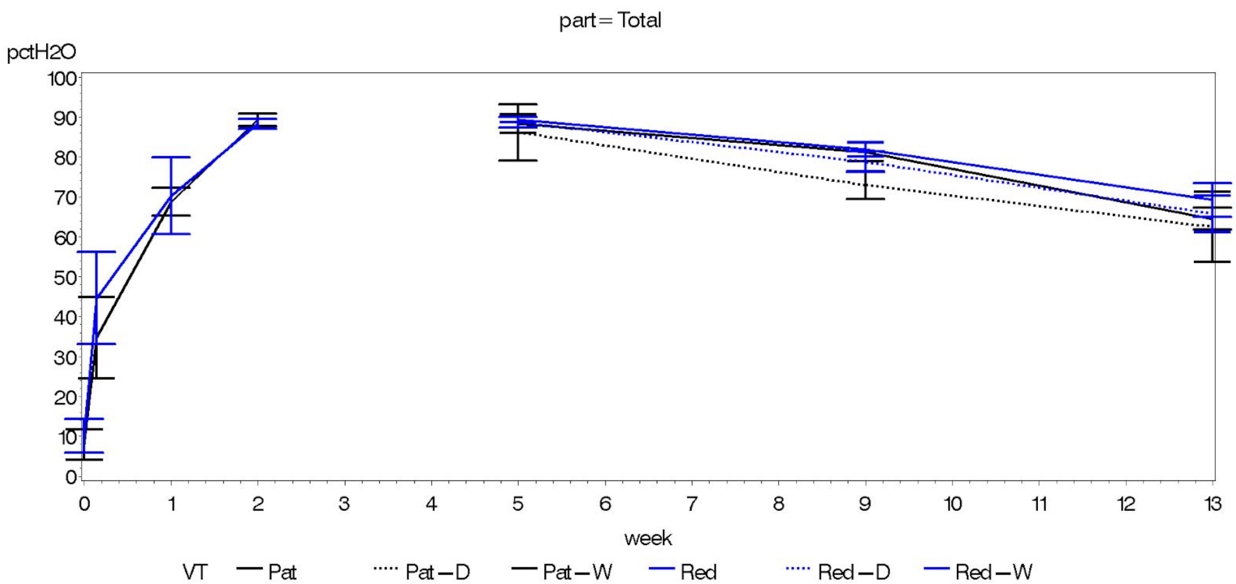

Figure 7. The graph above displays the Percent H2O for each development period with linear projections for each genotypic variety and treatment. H2O percentage from 0% to 100% can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Stem water potential provided a more precise mode of comparison for the state of internal water in these plants. The treatment significance level of less than .0001 in Table 12 told us that low water irrigation induced significantly more negative water potential than normal irrigation management or low nitrogen nutrition. Under these three different irrigation and nutrition management systems, Patwin displayed more negative stem water potential. This appears to indicate that under drought conditions, Central Red more effectively reduced transpiration and retained internal water content in comparison to Patwin.

Pr>F	Stem Water Pressure

Variety	<.0001
Treatment	<.0001
Variety x Treatment	0.086

Table 12. The table above presents the Pr>F statistics extracted from the Stem Water Pressure ANOVA table. The classes of comparison are found on the left most column.

Level of Var	Level of Treatment	N	SWP Mean	SWP Std Dev
Pat	LowN	5	-10.9260000	1.26407278
Pat	LowWater	5	-14.6000000	0.97979590
Pat	NormMgmt	5	-12.4560000	0.90676899
Red	LowN	5	-8.1480000	0.28349603
Red	LowWater	5	-10.8360000	1.09942258
Red	NormMgmt	5	-11.2160000	2.07114220

Table 13. The table above presents the stem water potential means from the raw data as it corresponds to each class. N signifies the number of test subjects in each class. The classes are indicated in the two leftmost column.

Leaf area was calculated for green, non-senescent leaves. In dry and wet conditions, Red demonstrated high means and very high standard deviations as seen in Figure 8 and Table 15. Since leaf area was intended to be an indicator of photosynthetic capacity, this lack of uniformity in Red's data makes conclusions about such productivity difficult. The effect of dry treatment on total leaf area for both varieties was profound and from visual observations we determined that leaf senescence and abscission was heavily affecting the dry treatment subjects. This was supported by our significant treatment statistic of 0.0004 in Table 14. Another related observation to be made here is that leaf area means generally decreased for every treatment in every variety from week 9 to week 13. This is not strongly supported by our statistics since standard deviations were very high but it appeared to be a trend in our visual observations as well. This could be due to the life cycle of wheat as, by week 13, the plants were approaching the ripening stage of maturation. This is visualized by the Zadoks scale in Figure 9.

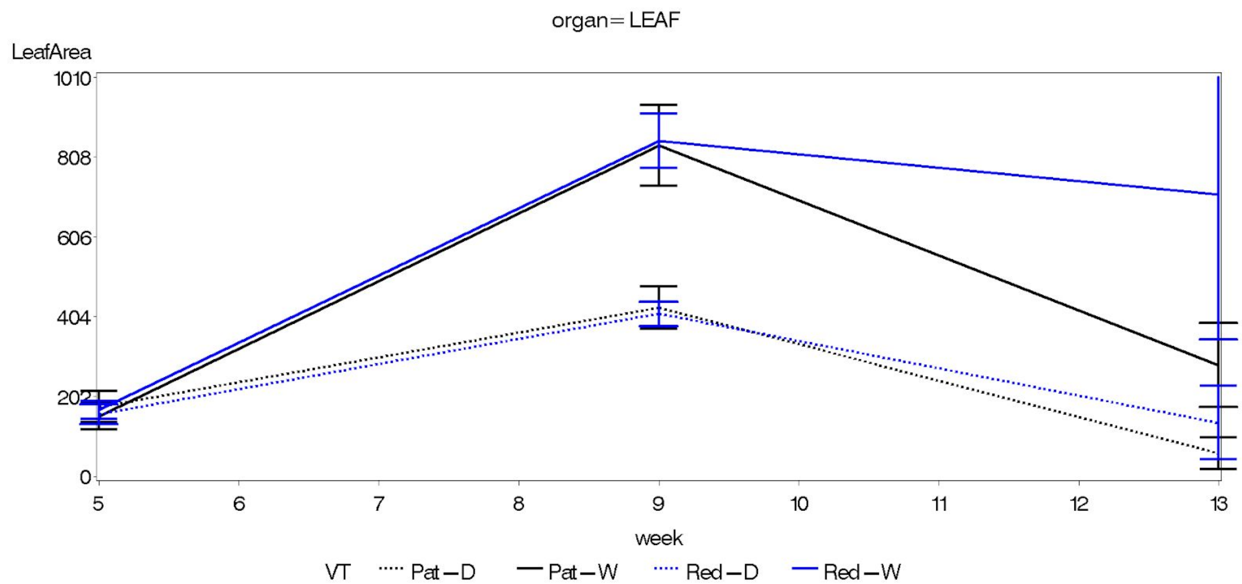

Figure 8. The graph above displays the leaf area for each development period with linear projections for each genotypic variety and treatment. Leaf area in cm sq can be found on the left-hand side with units in grams while time in increments by week is enumerated along the bottom.

Week 13	
Pr>F	Leaf Area
Variety	0.016
Treatment	0.0004
Variety x Treatment	0.084

Table 14. The table above presents the Pr>F statistics extracted from the Leaf Area ANOVA table. The classes of comparison are found on the left most column.

Level of Variety	Level of treatment	N	LeafArea	
			Mean	Std Dev
Pat	D	8	58.170000	56.810782
Pat	W	8	281.148750	150.123847
Red	D	8	135.403750	130.910750
Red	W	8	712.787500	519.784758

Table 15. The table above presents the Leaf Area means from the raw data as it corresponds to each class. N signifies the number of test subjects in each class. The classes are indicated in the two leftmost column.

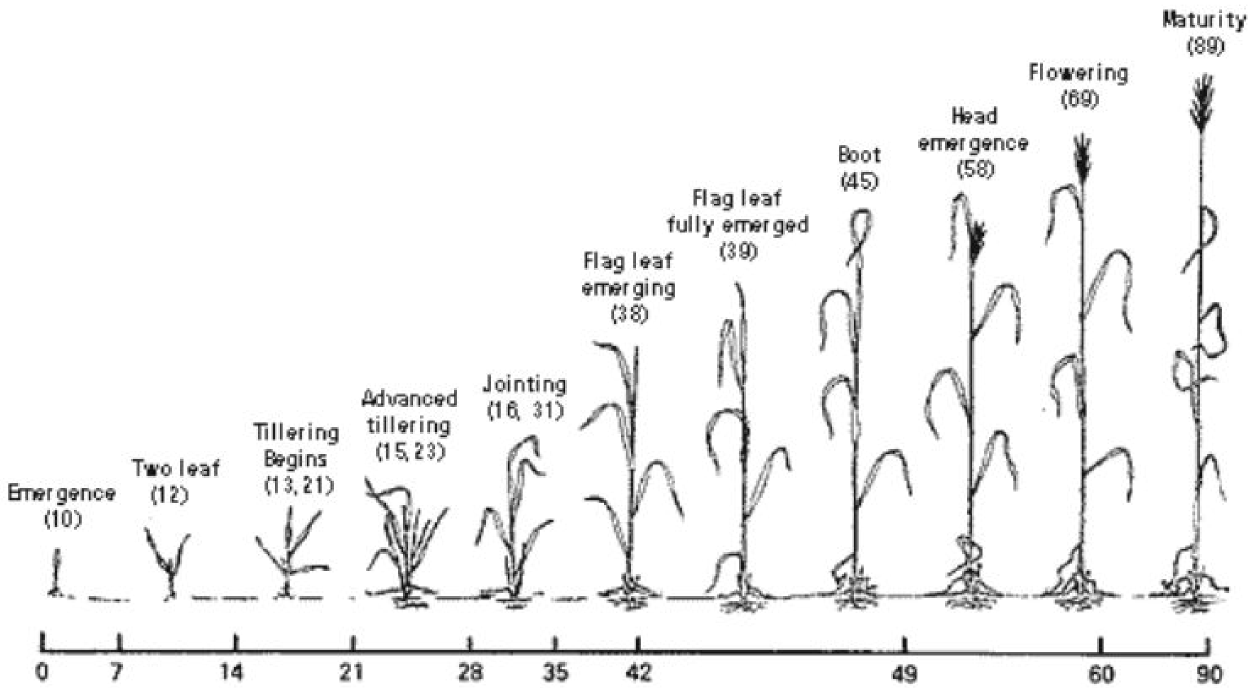

Figure 9. This visualization of the Zadoks scale was sourced from The Growth and Development Guide for Spring Wheat by the University of Minnesota Extension. 1995. http://www.extension.umn.edu/distribution/cropsystems/DC2547.html

Yield by Dry Weight

Yield by count is not the most informative measurement given the estimation process for determining total yield from yield per head, heads per tiller, and number of tillers. In this case we can refer to measurements of yield in dry weight, since it translates to productivity of grain harvest fairly directly.

Harvest index is a measurement of pounds of grain divided by total above-ground biomass. It was clear from Table 19 means and Table 16 significance values that Patwin had considerably higher harvest index in dry treatment than Central Red. This trend is further supported in results for yield per head dry weight. The variety significance in Table 17 and the means in Table 19 show that Patwin reported larger heads by dry weight in dry conditions. The mean yields per head were similar in wet conditions and the significant interaction of 0.005 tells us that dry treatments affected Red more severely in reduction of yield per head weight than Patwin. Dry weight of heads per dry weight of tillers represented in Table 18 and Table 19 indicates that Patwin sustained higher head production per tiller production in both wet and dry treatments.

Pr>F	Harvest Index Mean
Variety	0.004

Treatment	<.0001
Variety x Treatment	0.132

Table 16. The table above presents the Pr>F statistics extracted from the Harvest Index ANOVA table. The classes of comparison are found on the left most column.

Pr>F	Yield per Head Dry Weight
Variety	0.013
Treatment	<.0001
Variety x Treatment	0.005

Table 17. *The table above presents the Pr>F statistics extracted from the Yield per Head Dry Weight ANOVA table. The classes of comparison are found on the left most column.*

Pr>F	Dry Weight Heads Per Dry Weight Tiller
Variety	0.0005
Treatment	<.0001
Variety x Treatment	0.401

Table 18. *The table above presents the Pr>F statistics extracted from the Dry Weight Heads Per Dry Weight Tiller ANOVA table. The classes of comparison are found on the left most column.*

Level of Variety	Level of treatment	N	HarvIndex		YieldPerHeadDW		DWHeadsPerDWTiller	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Pat	D	8	0.14213509	0.07408984	0.37210356	0.13302185	1.05231217	0.30897312
Pat	W	8	0.29660329	0.06929775	0.56428736	0.06093688	1.79660313	0.49633458
Red	D	8	0.03751064	0.04398471	0.15932854	0.14285959	0.42177652	0.23229220
Red	W	8	0.26206269	0.06459882	0.57903563	0.05756864	1.39037055	0.39929296

Table 19. The table above presents the means from the raw data as it corresponds to each class. N signifies the number of test subjects in each class. The classes are indicated in the two leftmost column and the standards measurement in the row across the top.

Discussion

Our experiment indicates that Patwin has a superior ability to produce grain in terms of yield per head, head per tiller and number of heads and tillers in most conditions. When yields were similar in wet conditions, Patwin maintained its production of grain in dry conditions while Red's yields were further diminished. In the context of tiller and head count, Patwin had higher number in wet conditions while dry conditions induced similar results from both varieties. Patwin's relatively high yield per head and head per tiller was good evidence for its superiority for yield in dry conditions. In dry conditions, number of tillers was not significantly different between the two varieties and neither was shoot dry weight. This is further evidence for Red's limited ability to produce heads in drought conditions in comparison to Patwin.

Despite these conclusions, there is some advantages displayed by Central Red that warrant consideration. Drought resistance could be thought of as a pattern of behavior rather than an all out race for grain production. As far as demonstrating drought resistant responses to the environment goes, Central Red proved to undergo beneficial physiological changes in dry conditions, whether as a preventative response or induced as a result of the low water availability. Central Red's increased dry weight measurements were revealed to be the result of greater root growth in dry conditions, possibly a sign of an essential survival mechanism in drought. Where Central Red lacked in producing large heads, it excelled in maintaining internal water pressure conditions and reducing transpiration as evidenced by stem water potential measurements. Although it may have lagged behind in tiller and head production in wet conditions, it matched Patwin in dry conditions. At the end of week 13, it reported the most leaf area, another survivability trait. These facts may be supportive of the perspective that Central Red is truly the more drought resistant variety in this study. For plant breeders, these traits may be of particular interest in crosses with varieties of higher yields in order to imbue new lines with drought resistance. For agriculturalists, the ability of a crop to survive in a specific low-water climate despite lower yields might make Central Red an interesting option.