Comparing Pearl, Japanese, Foxtail, and Proso Millet Performance in the Californian Drought; Potential for a New Staple Crop

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ABSTRACT

Millet is a gluten-free whole grain consumed in various parts of the world. Certain millet varieties have been noted to have high yields in areas of drought. The following study is designed address the current lapse in quantitative data displaying the benefits of incorporating millet into Northern California's agricultural sector as a drought tolerant alternative crop. Pearl, Japanese, Foxtail, and Proso millet varieties were subject to three water conditions: Drought, Reduced and Full, the latter representing our control group. We took 25 samples for each water condition in all three varieties and plant height, number of ears per plant, ear length, and ear weight was recorded. Our findings indicated that of the three varieties, in two of the four growth parameter categories, there was no statistically significant difference in Pearl millet performance given different water inputs. Pearl millet was therefore the most resilient to water stress in the Gill Tract setting in comparison with Japanese and Foxtail millet.

KEYWORDS

Drought tolerance, alternative crop, whole grain, gluten –free, California microclimate

INTRODUCTION

In January 2015 governor Edmund Brown affirmed a drought state of emergency (Aillery 2015). The Department of Water Resources, California's Public Utilities Commission, and California's agricultural sector were advised to take immediate action to prevent and prepare for current and future water shortages. As California's drought continues, consumers and producers play a vital role in ensuring adequate water resources for current and future livelihoods. Since California's cultivators consume 90 % of the states groundwater, targeting the agricultural sector is of utmost importance (Aillery 2015). Therefore, a mechanism for reducing the percentage of water consumed through agriculture requires a shift away from water-intensive crop production to more viable and still profitable alternatives.

More specifically, programs that target the diversification and implementation of drought tolerant crops and seed varieties in California are of key interest in addressing the government's mandate (Springer 2007, Aillery and Schaible 2013). Currently, a number of research projects have been diverted to engineering drought tolerant crop varieties by identifying internal plant regulatory mechanisms for drought. However, less initiative has been taken to actually replace current water intensive crops with less intensive ones (Yang et al. 2010).

Millet, referred to as an ancient grain, is an ideal example of such a crop. Archeologists estimate that the cultivation of millet began in the Korean Peninsula before 3000 B.C. (Crawford and Gyoung 2003). Since then, the food source has spread amongst Eastern Asian nations and throughout Western and Southern Africa (Crawford 2006). Although the term millet is used to refer to a variety of grasses, millet used for consumption belongs to the grain family Poaceae and includes Pearl, Finger, Foxtail, Japanese, Proso, Kodo, Little, and Barnyard millet (Cowan and Watson 1997). Certain varieties of millet have been noted to have sufficient yields given drought conditions, suggesting less dependency on water consumption required for crop yield (Millet Network of India 2011). As an example, in 1987 the Pearl Millet Improvement Program conducted a study to identify the drought tolerance of Pearl millet by growing Pearl millet for three years within the dry seasons of February to May in Patancheru, India. The results indicated that in order for Pearl millet to have a high tolerance to drought, producers must consider time to flowering, proper development before exposure to intense drought, and millet breed type (Bidinger 1986). Broader studies done in West and East zones of Namibia suggest improved varieties of Pearl millet can be better suited for certain climates (Matayaire and Gupta 1996). Despite millet's proven qualities in India and Africa, little research has been done to determine the potential of millet as a commodity crop in a Northern California climate.

The following study is therefore designed to address the current lapse in quantitative data displaying the benefits of incorporating millet into Northern California's agricultural sector. Understanding how different varieties of millet perform in varying water conditions under a subset of California's microclimates could identify which millet varieties are of practical growth in California. In order to determine this, our study will test the performance of three millet varieties currently available in the U.S market: Japanese, Pearl, and Foxtail millet under varying water conditions in Albany, California. We hypothesize that given the successful results and the literature supporting drought tolerance of Pearl millet, it will be most suitable in a Northern Californian microclimate.

METHODS

Study Site

In order to evaluate the drought tolerant capability of millets in the Bay Area region, California, US, we conducted a small study on the growth of Japanese, Pearl, Foxtail, and Proso millet. The study was conducted at the UC Gill Tract Farm in Albany, California beginning May 19th, 2015 and ending on October 30th, 2015. The seeds were sourced from Albert Lea Seed**.** No fertilizers or pesticides were used. Total millet cultivation area was 20 feet wide and 200 feet long. Four plots were set up at the Gill Tract each containing one of the above varieties of millet.

Table 1. Plot design for Pearl, Japanese, Foxtail, and Proso Millet.

Row #	Watering Regime	Treatment
1	Once a week: May 19th and May 22nd (2 times)	Drought
2	Once a week: May 19th to June 25th (6 times)	Reduced

3-5	Once a week: May 19th to October 30th (24 times)	Full

In each row, we sowed 8-10 seeds every ten inches using hand planters. The seeds were planted 1-2 inches deep and immediately covered with Reemay to keep pests out and conserve moisture during the germination process. The crops that previously occupied the test plot included sorghum and corn and a soil pH range was 5.5 – 6.5, ideal for the varieties of millet we grew (USDA 2015). The drip at Gill was on an average of 6 hours (9am to 3pm) on Fridays, until mid-August, when it was switched to Thursdays. Rows 3 to 5 represented our control group.

Metadata

Alongside the field study we collected vital metadata using the United States Department of Agriculture Farm Data and the U.S. Department of Commerce Annual Climatological Survey in order to determine what external factors contributed in enabling or disabling the growth of millet. This included:

- farm size (m)
- millet cultivation area (m)
- previously grown crops
- average rainfall during cultivation (inch.)
- average temperature during cultivation (degrees Fahrenheit)
- soil acidity
- signs of plant infection

Measurements

On October 30, 2015, 25 random samples were taken from each water condition for each variety. For these 25 random samples we measured:

- Plant height (cm)
- Number of millet ears per plant
- Millet ear lenght (cm)

- Millet ear weight (g)

Analysis Methods

I used Microsoft Excel to determine means, standard deviation, and standard error of the mean for each parameter measured. Histograms containing error bars were used to convey the measurements. To test for normality of our data I performed the Shapiro-Wilk test using the Version 22.0 SPSS software. A parametric study was then used to determine if any relationships could be established between water input and millet growth. Because observations were independent, contained a homogeneity of variances, and given that my data was normal, I used an ANOVA test by the post hoc Tukey test. P-values < 0.05 were considered statistically significant.

RESULTS

Metadata Results

To survey the external factors affecting the growth of millet metadata was collected. Total rainfall during cultivation was .2 inches while temperature range was 58.2 – 69.4 degrees Fahrenheit (DOC 2015). The farm was monitored once a week and there were no signs of plant infection. The following results only consider information from Pearl, Japanese, and Foxtail millet since Proso millet did not grow.

Growth Charts

The results for the mean, standard deviation, and standard error of the mean for each growth parameter, variety, and condition are displayed in the charts (see Appendix A) . In all three varieties the Full condition mean is greater than Drought, and Reduced (Table 1). The data conveys a large variation in standard deviations across varieties but not necessarily for condition (Table 2). Across lengths the mean varies with different varieties. The mean for Japanese millet drought and full groups are very similar. In table 3, standard deviations for Pearl and Foxtail Millet were relatively similar. There is a gradient in ear length in accordance with gradient of water applied.

And in Table 4, data points for foxtail drought do not exist since the turkeys ate the millet. Gradient is seen in ear weight as well.

Histograms to Visualize Data from Growth Charts

I formulated histograms to visualize the results from the analysis in Microsoft Excel. Error bars represent standard error.

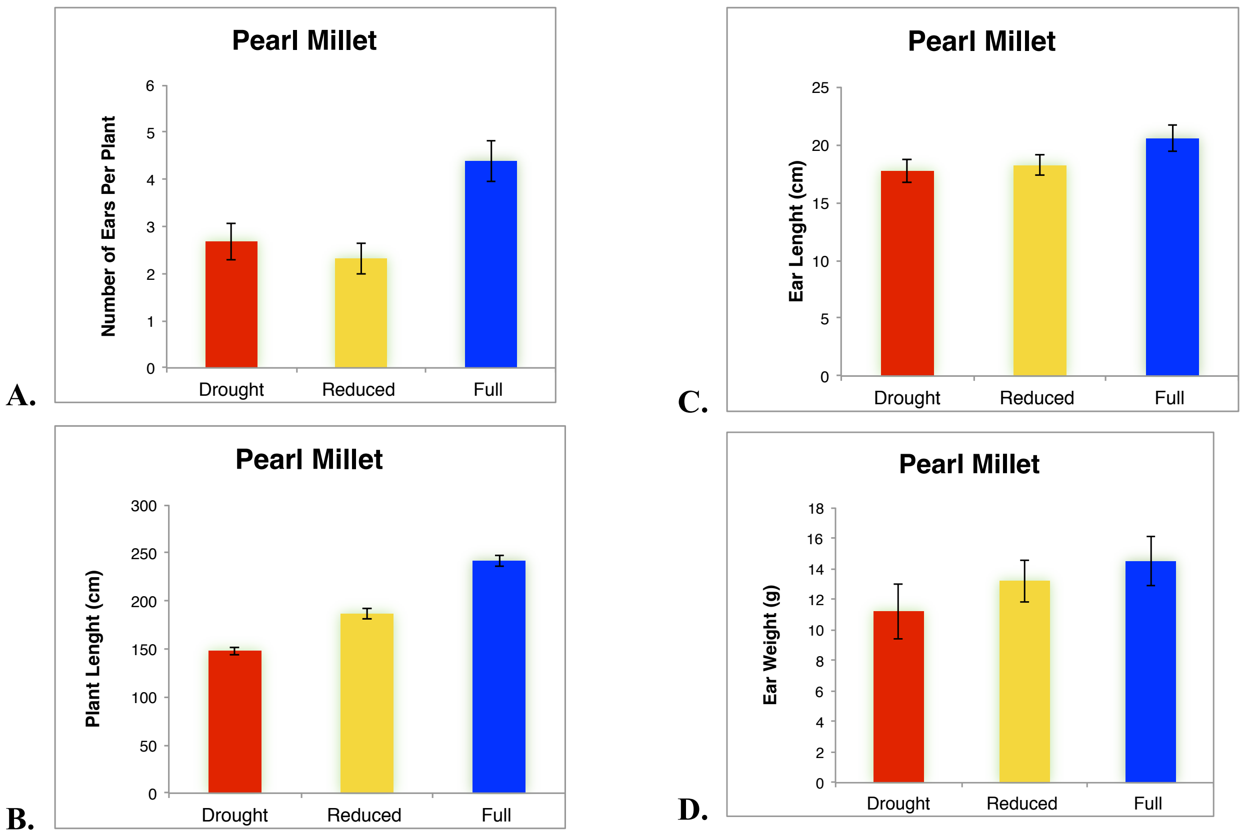

Figure 1: Pearl millet measurements under different water conditions: A. number of ears per plant; B. plant lenght; C. ear length; D. ear weight.

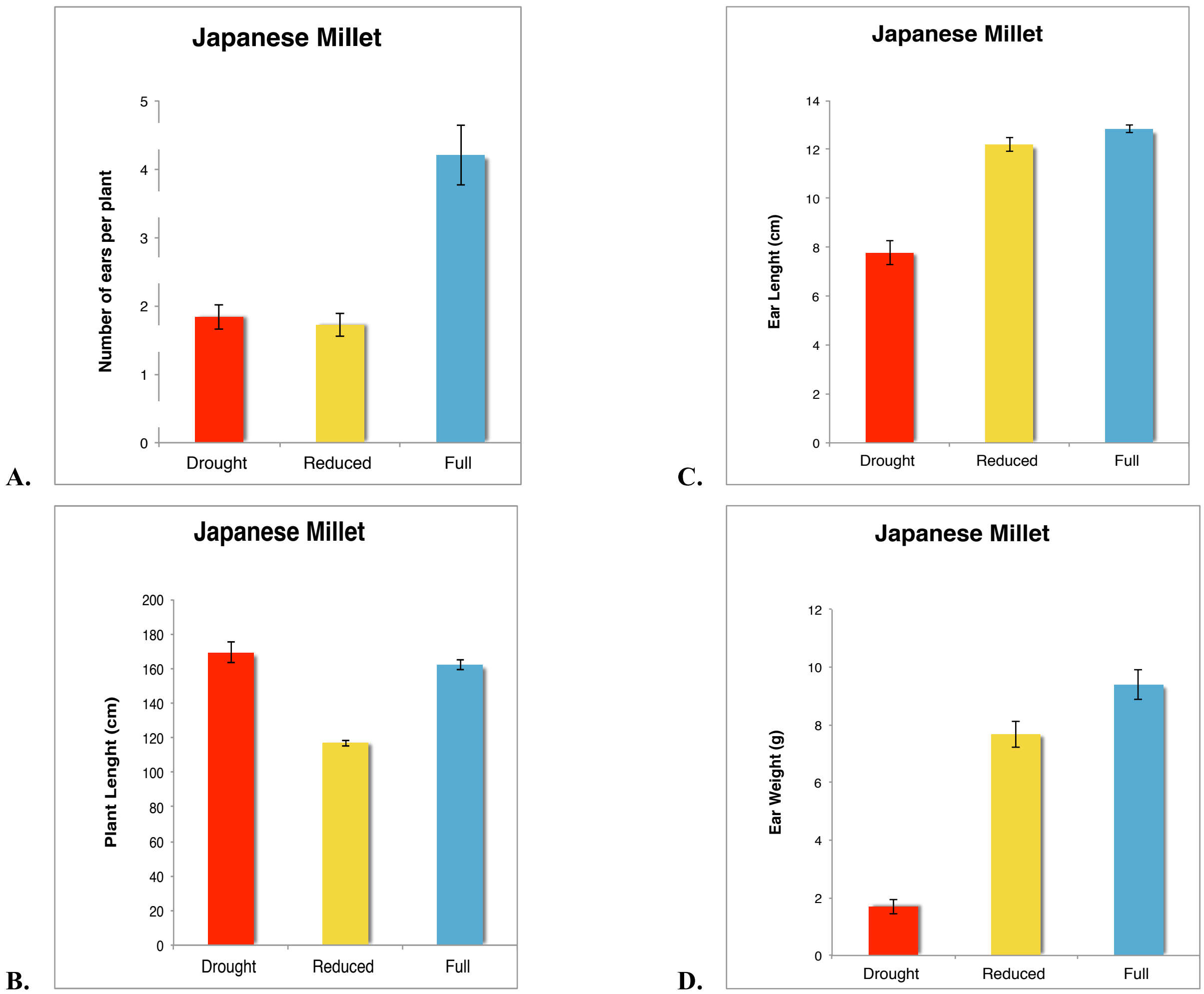

Figure 2: Japanese millet measurements under different water conditions: A. number of ears per plant; B. plant lenght; C. ear length; D. ear weight.

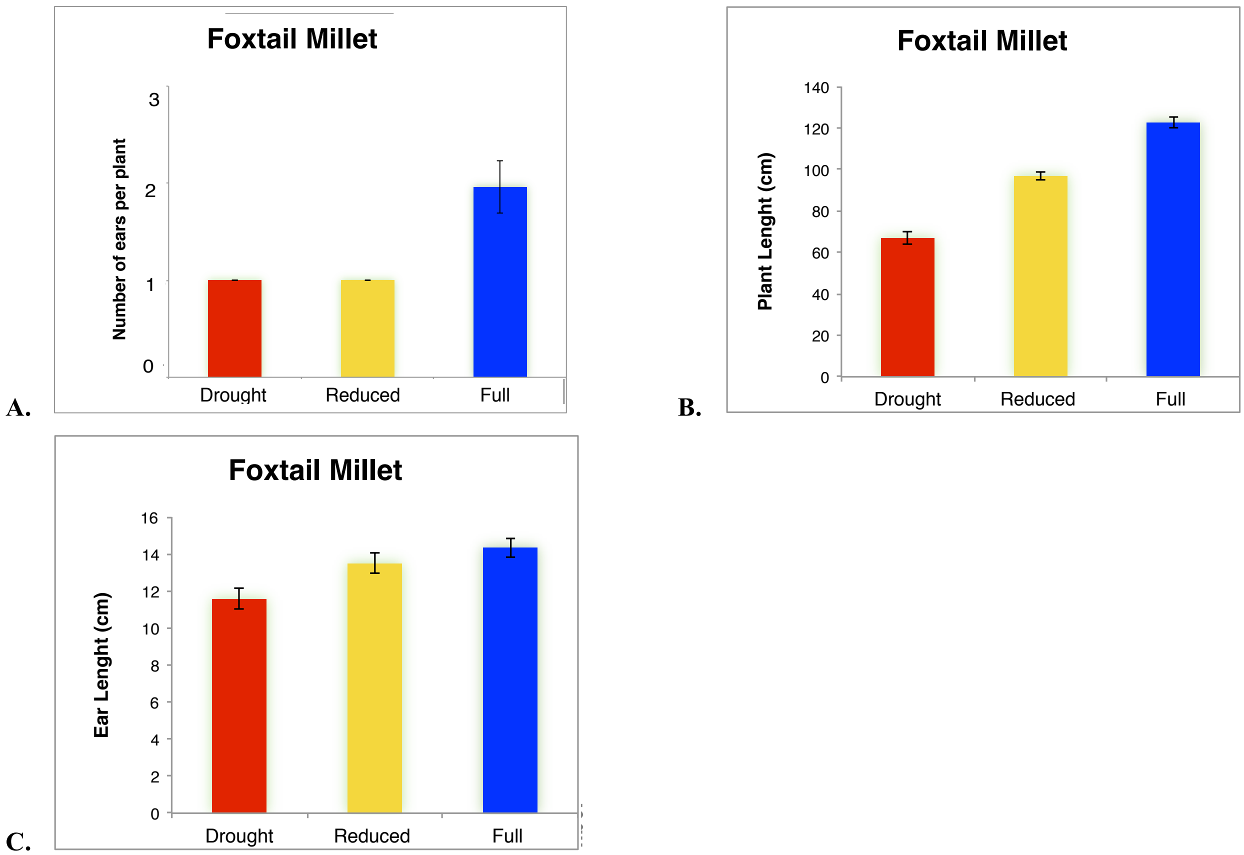

Figure 3: Foxtail millet measurements under different water conditions: A. number of ears per plant; B. plant lenght; C. ear length.

Figure 1 indicates similarities in ear length and ear weight across all three conditions. In Figure 1A drought and reduced conditions seem to have similar results while in 1B a gradient is observed. In Figure 2 I observed that the Full condition on avergae had more ears per plant than drought and reduced conditions, ear length is similar in the reduced and full conditions, and that there is a gradient seen with ear weight in Japanese millet. For Figure 3, I noted that the full condition on average had more ears per plant than drought and reduced conditions. In addition, the ear length of the full and reduced conditions were similar while there was a gradient in plant length with differing water conditions.

Statistical Analysis

Table 5: P-values from Tukey Test for each water condition and millet measurement parameter

	Plant Length	Number of Ears	Ear Length	Ear Weight
Pearl	.000 (drought) .000 (reduced)	.026 (drought) .006 (reduced)	.114 (drought) .222 (reduced)	.323 (drought) .837 (reduced)
Japanese	.379 (drought) .000 (reduced)	.000 (drought) .000 (reduced)	.000 (drought) .387 (reduced)	.000 (drought) .016 (reduced)
Foxtail	.000 (drought) .000 (reduced)	.000 (drought) .000 (reduced)	.001 (drought) .486 (reduced)	N/A

In every dataset, the Shapiro Wilk test indicated a p-value greater than the chosen alpha level of .05. I therefore accepted the null hypothesis entailing that the data follows a normal distribution. I performed an ANOVA and post hoc Tukey test to determine if in a given condition there were any groups (e.g. drought and full) which were not considered statistically different from the Full water condition, which was used as the reference. Applying the ANOVA and Tukey, the null hypothesis stated there is no difference between the groups being compared (e.g. reduced and full). I rejected the null hypothesis where $p < .05$. The Full water condition was chosen as the reference condition to assess significant difference between groups; the first number in each cell of Table 5 refers to the drought group and the second number to the reduced water group. P-values $< .05$ were considered statistically significant. From our data in Table 5 I observed that ear length and ear weight for the Pearl variety, and ear length for Japanese and Foxtail varieties show statistically significant results.

Across growth parameters, in similarity to the control, millet varieties yielded following results. Japanese millet showed the greatest similarity to the control group while Pearl and Foxtail were both not statistically similar to the control. For number of ears, Pearl millet was statistically similar to the control while Japanese and Foxtail millet were not. A higher water input is therefore required to produce more than one ear per plant for the Japanese and Foxtail varieties. With ear length, the Foxtail reduced group had the greatest similarity to the control followed by Japanese reduced, Pearl reduced and Pearl drought. With ear weight, Pearl reduced and drought were statistically similar to the control.

Discussion

Our findings indicated that of the three varieties, in two of the four growth parameter categories, Pearl millet performed very similarly in Drought, Reduced, and Full water conditions. Pearl millet was therefore the most resilient to water stress in the Gill Tract setting in comparison with Japanese and Foxtail millet.

In the Pearl millet, plant length and number of ears were primarily affected in comparison with the full control group. While plant length is irrelevant in describing the millet yield, the number of ears do have an impact on affecting the yield of crop. Ear length and ear weight however were statistically very similar in drought, reduced, and full conditions. A synthesis of this data conveys that overall Pearl millet has the ability to grow successfully in both drought and reduced conditions.

In Japanese millet, the reduced ear length category was statistically very similar to the control and the ear weight category also revealed statistically similar results. An interesting data point was found in the plant length category where the drought group was more statistically similar to the control than the reduced group. We believe this was due to a difference in planting densities between the three water conditions in the Japanese millet since in other millet varieties such as Foxtail millet, planting density over 100 hills/ m^2 can significantly affect the manner in which millet grows (Maobe et al. 2014).

Foxtail millet drought and reduced groups were not statistically similar to the control in the plant length and number of ears categories. Ear length in the reduced condition was the only significant category and data points were not available for ear weight so no conclusions could be made on this parameter.

While Pearl millet indicated favorable results, studies suggest even better performance of Pearl, Japanese, and Foxtail millet at soil temperatures higher than 65 degrees Fahrenheit (Gregory 1986). Therefore, delaying planting a few weeks until temperatures were higher could yield even more successful results. However, both the reduced and drought categories grew less number of ears in all three varieties. A reduced watering regime therefore reduces the ears per plant; these results are consistent with other grains too such as wheat (Shirazi et al. 2014). Planting density also plays an important role in determining how successful the plants will perform as seen with the Proso millet species which did not grow due to competition between seeds planted too close to one another.

Limitations

Limitations in this study have to do with having access to only a few varieties of millet seeds available in the US market and therefore being able to test only a few of the many existing consumable varieties of millet. In addition, since ideal seed density was not considered, the Proso millet did not grow. In addition, no data points were available for Foxtail millet ear weight, so a complete analysis of this variety could not be made.

Implications and Future Directions

This study provides insight on how millet is able to perform in a microclimate specific to the Bay Area. The results convey feasible results for Pearl millet to undergo small scale cultivation in the Bay Area given the applied reduced watering regime. Millet is currently very limited in use in the general consumer diets of Bay Area residents. With current water limitations due to drought and seasonal rain cycles, millet can be explored as a dietary substitute for water intensive Californian grown grains in an attempt to reduce agricultural water use.

In addition, these findings are appropriate to use as a pilot study for a broader study, which would test the following varieties as well as additional millet varieties in different microclimates, such as in the Central Valley where large scale cultivation occurs. Future studies can prevent invasive species and pests from eating millet crops through an improvement in planting technique. A revised research question could ask how particular varieties of millet perform under varying microclimates: in differing watering regimes, humidity, gradient temperatures, and soil composition. Given this studies' conclusion on the resilience of Pearl millet, repeating this experiment with additional variables will help confirm these results.

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APPENDIX A: Growth Charts

Table 1. Plant Length across conditions and varieties.

Variety	Condition	Mean	Standard Deviation	Standard Error
Pearl	Drought	148.02	19.8	3.96
Pearl	Reduced	186.74	26.62	5.32
Pearl	Full	241.71	27.60	5.52
Japanese	Drought	169.27	28.84	5.77
Japanese	Reduced	116.96	8.57	1.71
Japanese	Full	162.08	13.30	2.66
Foxtail	Drought	67.00	15.00	3.01
Foxtail	Reduced	96.88	9.91	1.98
Foxtail	Full	122.56	12.17	2.43

Table 2. Number of Ears across conditions and varieties.

Variety	Condition	Mean	Standard Deviation	Standard Error
Pearl	Drought	2.68	1.93	0.39
Pearl	Reduced	2.32	1.65	0.33
Pearl	Full	4.38	2.14	0.43
Japanese	Drought	1.84	0.90	0.18
Japanese	Reduced	1.72	0.84	0.17
Japanese	Full	4.20	2.16	0.43

Foxtail	Drought	1.00	0.00	0.00
Foxtail	Reduced	1.00	0.00	0.00
Foxtail	Full	1.96	1.34	.27

Table 3. Ear Length across conditions and varieties.

Variety	Condition	Mean	Standard Deviation	Standard Error
Pearl	Drought	17.72	4.85	0.97
Pearl	Reduced	18.20	4.34	0.87
Pearl	Full	20.54	5.52	1.10
Japanese	Drought	7.76	2.45	0.49
Japanese	Reduced	12.20	1.38	0.28
Japanese	Full	12.83	0.78	0.16
Foxtail	Drought	11.57	2.73	0.55
Foxtail	Reduced	13.49	2.63	0.53
Foxtail	Full	14.34	2.77	0.51

Table 4. Ear Weight across conditions and varieties.

Variety	Condition	Mean	Standard Deviation	Standard Error
Pearl	Drought	11.21	8.98	1.80
Pearl	Reduced	13.20	6.98	1.40
Pearl	Full	14.49	8.01	1.60
Japanese	Drought	1.69	1.26	0.25
Japanese	Reduced	7.76	2.32	0.46
Japanese	Full	9.39	2.53	0.51
Foxtail	Drought	N/A	N/A	N/A
Foxtail	Reduced	2.38	1.87	N/A
Foxtail	Full	5.04	2.24	0.75