Drought Stress Analysis

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Introduction

Due to unfavourable environmental conditions plants are subjected to various abiotic and biotic stressed affecting their growth, metabolism and yield. Drought is one of major abiotic stressed constraining crop productivity worlwide. It reduces plant productivity by inhibiting growth and slows growth, induces stomatal closure and therefore reduces photosynthesis.

Drought tolerance is the ability to which a plant maintains its biomass production during arid or drought conditions. Some plants are naturally adapted to dry conditions, surviving with protection mechanisms such as desiccation tolerance, detoxification, or repair of xylem embolism. Other plants, specifically crops like corn, wheat, and rice, have become increasingly tolerant to drought with new varieties created via genetic engineering.Plants can be subjected to slowly developing water shortages (ie, taking days, weeks, or months), or they may face short-term deficits of water (ie, hours to days). In these situations, plants adapt by responding accordingly, minimizing water loss and maximizing water uptake.

Research into the molecular pathways involving stress tolerance have revealed that overexpression of such genes can enhance drought tolerance, leading to projects focused on the development of transgenic crop varieties.

Polyethylene glycol (PEG-6000) is mainly used for the determination of the drought stress related information's from the plants. Polyethylene glycol(PEG-6000) generates osmotic stress which reduces photosynthetic rate, which later effects chlorophyll-a and chlorophyll-b contents, any stress to the plant effects mechanism of photosynthesis at cellular level which includes pigments, photosystems, the electron transport system and co2 reduction pathways and reduce photosynthesis.

'Sorghum bicolor' (Jowar) is very much adaptive to drought conditions but the level of adaptiveness varies among it's various varieties along with the increase in severity of drought
This project is based on the comparison of the genotypic variation in photosynthetic competence of 11 varieties of 'Sorghum bicolor' plant during drought.

Here we are testing 11 varieties of Sorghum bicolor by applying various concentrations of PolyEthyl Glycol (from 0% to 25%) to them and observe how the various genotypes change for each variety

Data preparation:

For convinience, the data is converted into a more suitable form. Below is a small view of how the form of the data is changed.

RWC	CO2	Cond	Int	PEG	Variety
96.80	2.72	59.50	337.10	0	E36-1
96.20	2.92	89.80	341.30	0	E36-1
95.80	3.40	71.00	354.70	0	E36-1
94.80	8.03	73.20	194.10	0	ICSV 745
96.10	7.09	78.30	241.50	0	ICSV 745
92.90	6.08	86.10	211.90	0	ICSV 745

Below is the listed information that we get from the data set.

- There are total 6 different concentrations of Polyethylene Glycol applied (0, 0.05, 0.10, 0.15, 0.20, 0.25)
- 6 PEG concentrations are applied to 11 varieties of 'Sorghum bicolor' viz. E36-1, ICSV 745, IS 9830, IS 18551, IS22380, M35-1, N13, PB1588-3, R 16, Tx7078 and 296B
- 4 responses viz. "Relative Water content", "CO2 Fixation rate", "Conductance" and "Intracellular CO2 Conc."; have been collected from this experiment for each PEG concentration and for each variety of 'Sorghum bicolor'
- For each variety and each PEG concentration, the experiment is conducted 3 times.

Data Preprocessing

Changing the data type

While converting the data to a more suitable form for analysis, it was observed that the data type for all data regarding the four responses were character, even though they are quantitative entries. Conversion of the data type is performed for them. Further the Varieties of 'Sorghum Bicolor' and PEG concentration values are converted to factor variables instead of just keeping them as character and numerical values respectively

Presence of missing values

The presence of 4 missing responses in a trial for PEG concentration 0.15 and Variety R16 and also 3 missing responses in a trial for PEG conc. 0.2 and Variety M35-1, is detected. Since each experiment is repeated only 3 times, so instead of just ignoring the presence of missing data, the mean of the two other responses are imputed in the respective data cells

Now, keeping PEG concentration fixed, in order to compare the 11 varieties, the data is further divided into 6 parts, each part consisting of the response values for each variety.

Data Exploration

Further exploration is done through graphs

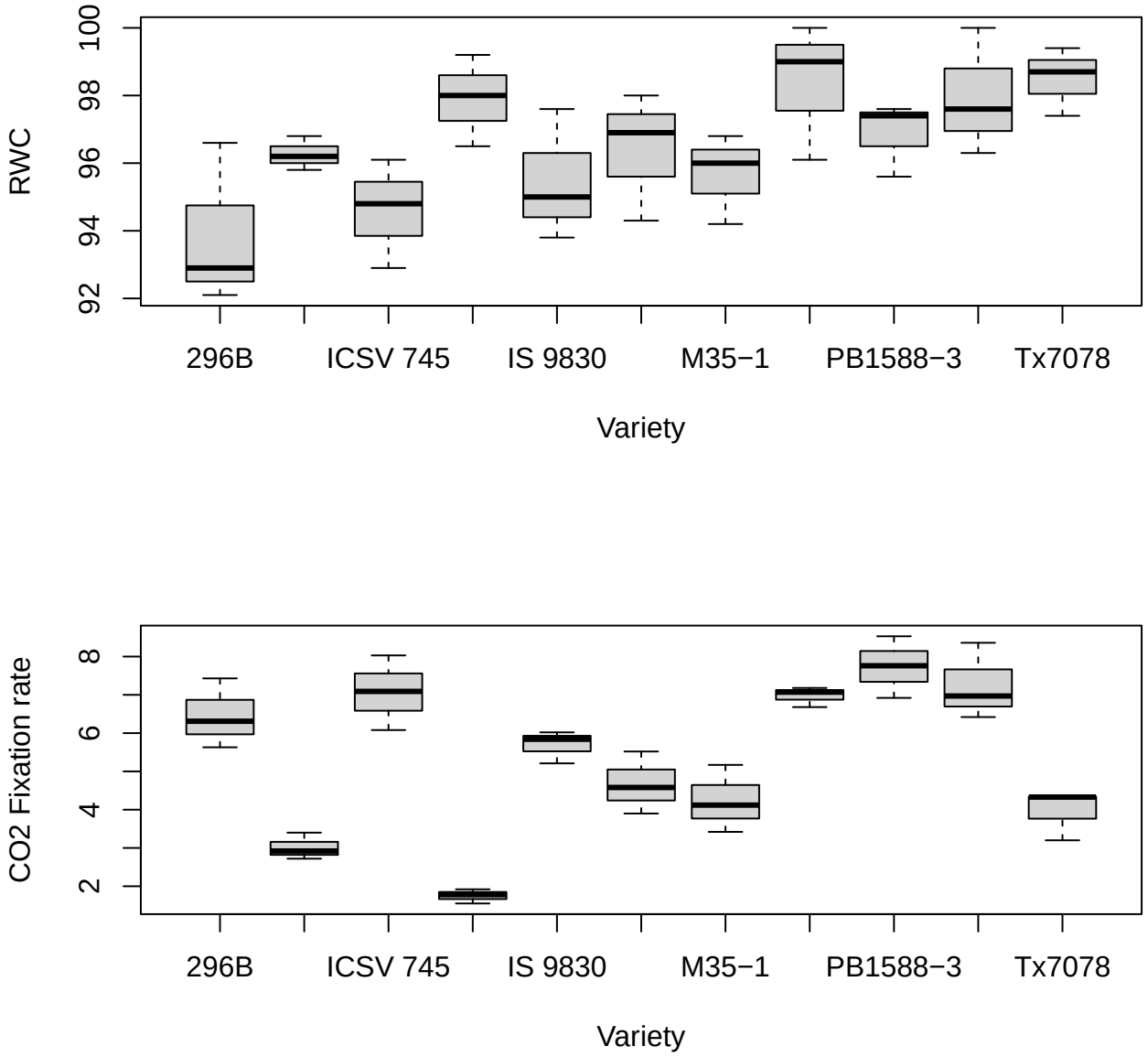

Figure 1: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when no PEG is applied.*

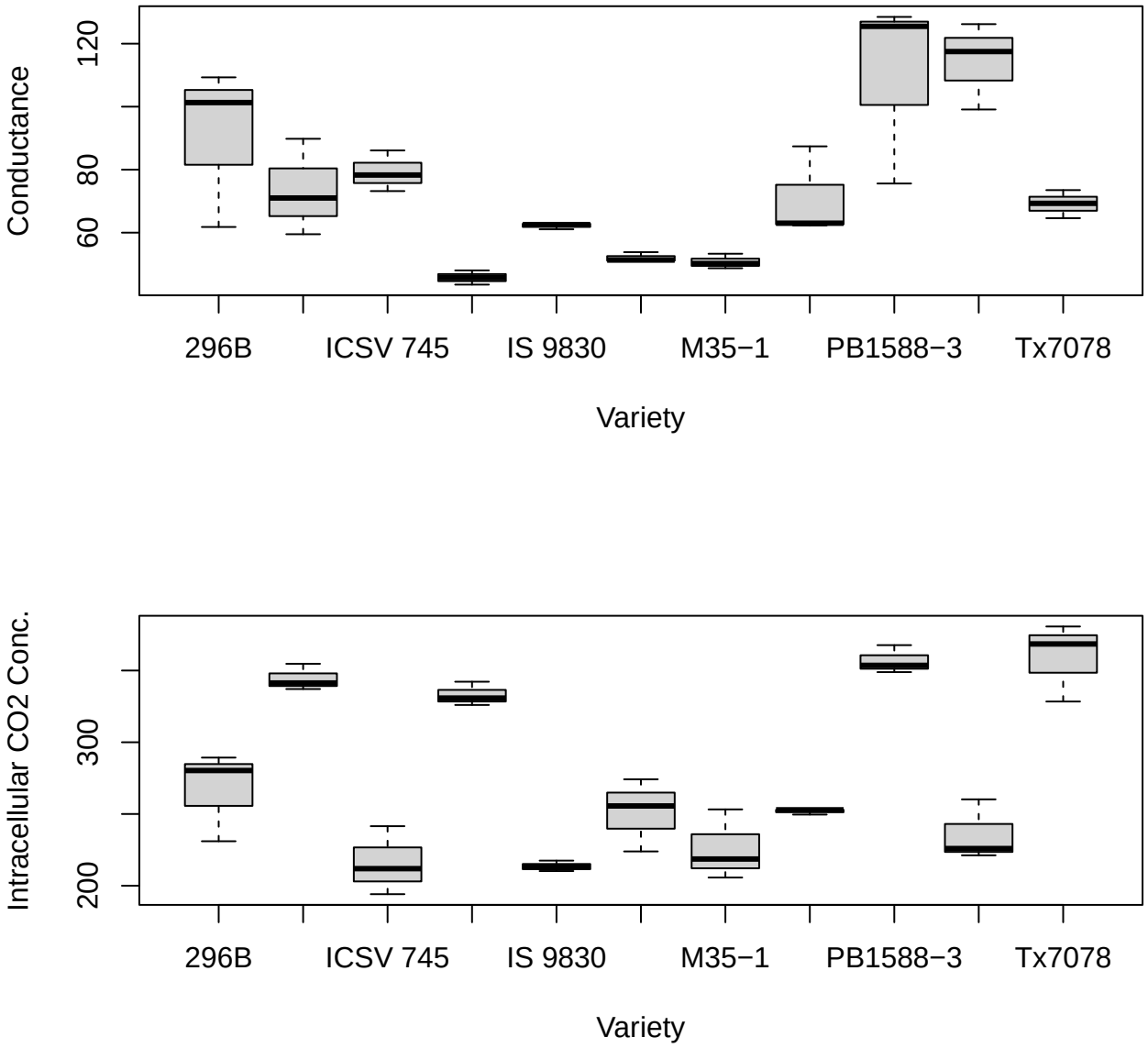

Figure 2: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when no PEG is applied.*

Variety	RWC	CO2	Cond	Int
296B : 3	Min. : 92.10	Min. :1.550	Min. : 43.50	Min. :194.1
E36-1 : 3	1st Qu.: 95.60	1st Qu.:3.900	1st Qu.: 53.80	1st Qu.:223.9
ICSV 745: 3	Median : 96.60	Median :5.630	Median : 64.60	Median :255.6
IS 18551: 3	Mean : 96.53	Mean :5.345	Mean : 74.39	Mean :277.6
IS 9830 : 3	3rd Qu.: 97.60	3rd Qu.:6.970	3rd Qu.: 87.40	3rd Qu.:337.1
IS22380 : 3	Max. :100.00	Max. :8.530	Max. :128.50	Max. :380.7
(Other) :15				

PEG conc. 0

From the summary ,we observe that apart from "Relative water content", the variation of the other three responses are quiet large among the varieties. Boxplots are provided to futher picturize this

As stated earlier that for each variety and each PEG concentration, the experiment is repeated 3 times. From the box plots we observe, that for the response variable "Conductance", the three data points vary a lot among themselves for some varieties.

When the PEG concentration is 0, that is under normal conditions from the available data comparisions of the varieties based on the four response variables are done.

(Refer to Figure 1 on page 3)

- **Relative water content**: Among the 11 varieties, 'N13' has the highest 'RWC' and '296B' having the lowest . There is not much variation in the 'RWC' of the varieties.
- **CO_2 Fixation rate:** 'PB1588-3' has the highest while 'IS 18551' has the lowest. The variation of the CO_2 fixation rate, apart from one or two varieties are quite different from each other

(Refer to Figure 2 on the previous page)

- **Conductance**: 'PB1588-3' has the highest while 'IS 18551' has the lowest. There is huge difference in the observations for 'PB1588-3', '296B' inspite of mainting the exact same conditions
- **Intracellular CO_2 conc**. : 'PB1588-3' and 'Tx7078' have the highest conc and ICSV 745 having the lowest. For some varieties there is a comparitively large difference in the observations recorded

PEG conc. 0.05

From the summary data in page 8, it is observed that the variation of the responses are almost same as the variation when no PEG was applied. For "CO_2 Fixation rate" and "Conductance" there is an increase in all the statistics while for "Intracellular CO_2 conc." there is a decrease in the statistics, when compare to the summary stats where no PEG was applied. For each response we compare the varieties.

From the available data, comparisions among the varieties based on the four response variables are done:

(Refer to Figure 3 on the following page)

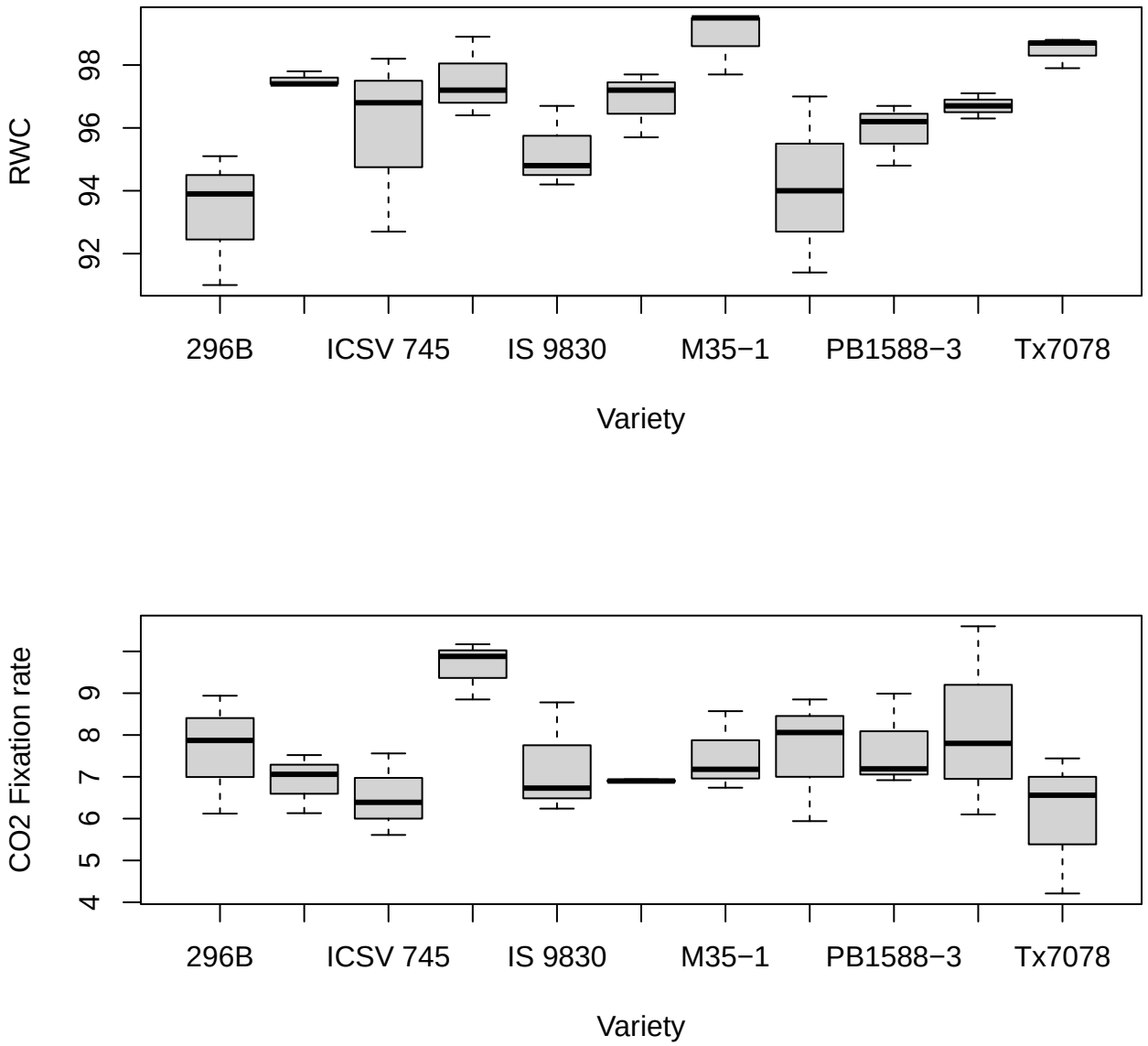

Figure 3: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when PEG conc. is 0.05*

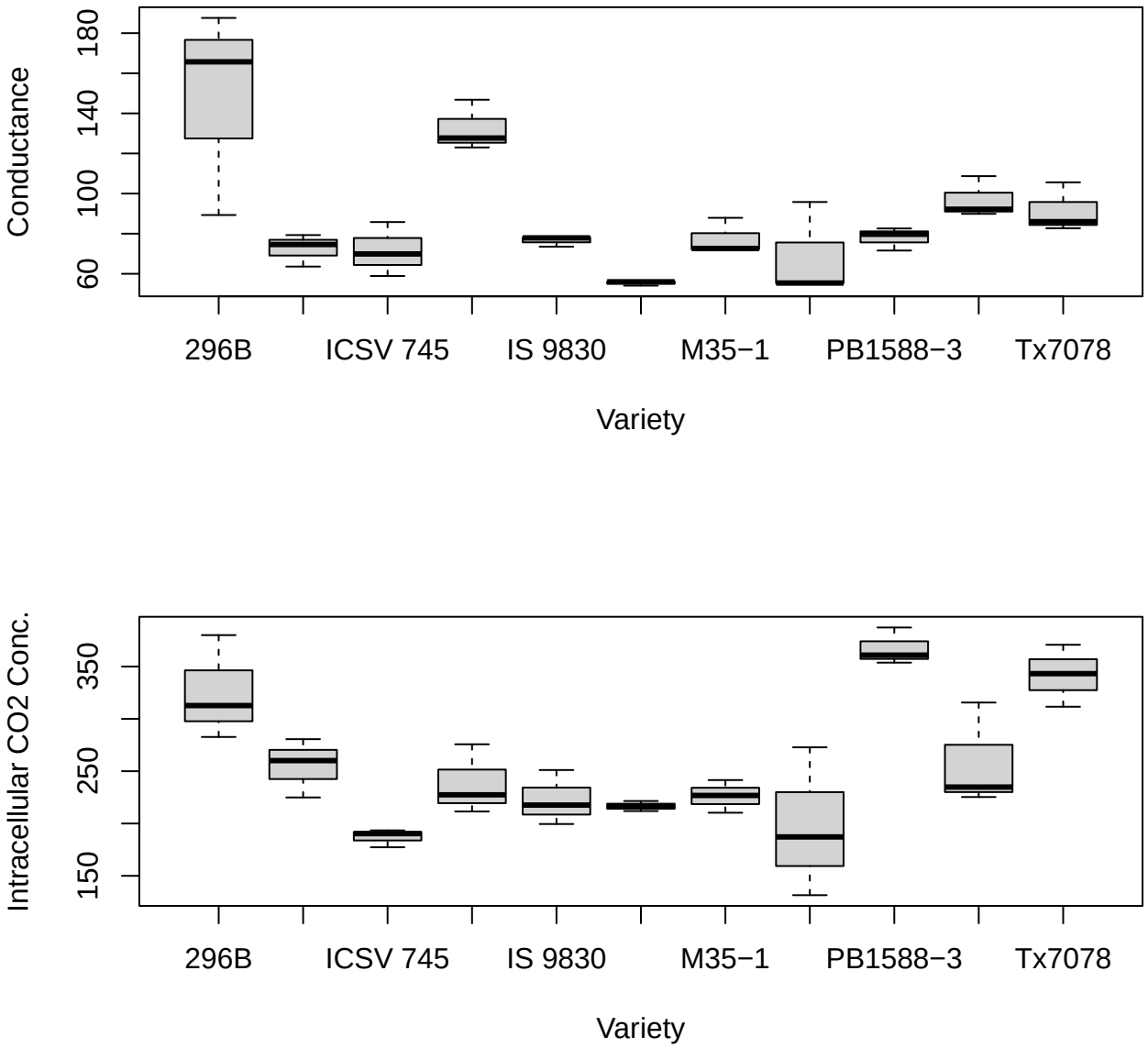

Figure 4: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when PEG conc. is 0.05.*

Variety	RWC	CO2	Cond	Int
296B : 3	Min. :91.00	Min. : 4.210	Min. : 54.10	Min. :131.5
E36-1 : 3	1st Qu.:95.10	1st Qu.: 6.560	1st Qu.: 71.60	1st Qu.:211.9
ICSV 745: 3	Median :96.80	Median : 7.180	Median : 79.70	Median :234.8
IS 18551: 3	Mean :96.41	Mean : 7.446	Mean : 88.07	Mean :257.8
IS 9830 : 3	3rd Qu.:97.70	3rd Qu.: 8.570	3rd Qu.: 92.20	3rd Qu.:311.6
IS22380 : 3	Max. :99.50	Max. :10.600	Max. :187.60	Max. :387.3
(Other) :15				

- **Relative water content**: Under normal conditions we observed N13 having the highest relative water content, but when the concentration is increased to 0.05, we observe N13 to have one of the lowest relative water content. Here the relative water content of M35-1 has increased significantly , having the highest relative water content. 296B still has the lowest relative water content. Also there is an increase in the relative water content of ICSV 745
- **CO_2 Fixation rate**: A significant increase in CO_2 fixation rate is observed for varieties E36-1, IS 18551, IS22380,M35-1 and Tx7078. R16 and IS18551 have a high CO_2 fixation rate and Tx7078 having the lowest.

(Refer to Figure 4 on the previous page)

- **Conductance**: We observe a significant increase as well as decrease in the conductance of the varities. For PB1588-3, the conductance has decreased while for 296B the conductance increased and has the highest conductance. IS 18551, which had the lowest conductance showed a significant increase in the conductance level.
- **Intracellular CO_2 conc.** : PB1588-3 and Tx7078 still have a comparitively higher Intracellular CO_2 conc. than the others. For varieties like E36-1 and IS 18551, the conc. decreased while for 296B and R16 it increased. For others it remained more or less same.

PEG conc. 0.1

Variety	RWC	CO2	Cond	Int
296B : 3	Min. :86.40	Min. :3.510	Min. : 34.70	Min. :152.9
E36-1 : 3	1st Qu.:94.20	1st Qu.:6.350	1st Qu.: 60.80	1st Qu.:192.2
ICSV 745: 3	Median :95.50	Median :7.500	Median : 67.30	Median :215.9
IS 18551: 3	Mean :94.93	Mean :7.055	Mean : 68.64	Mean :221.4
IS 9830 : 3	3rd Qu.:97.20	3rd Qu.:8.060	3rd Qu.: 78.40	3rd Qu.:249.3
IS22380 : 3	Max. :99.40	Max. :9.180	Max. :101.80	Max. :302.5
(Other) :15				

There is a decrease in the total variation of the Intracellular CO_2 conc. while a slight increase in the variation of the Relative Water Content compared to the data for PEG concentration 0.05. We create boxplots for further visualisations

From the available data, comparisions among the varieties based on the four response variables are done:

(Refer to Figure 5 on the following page)

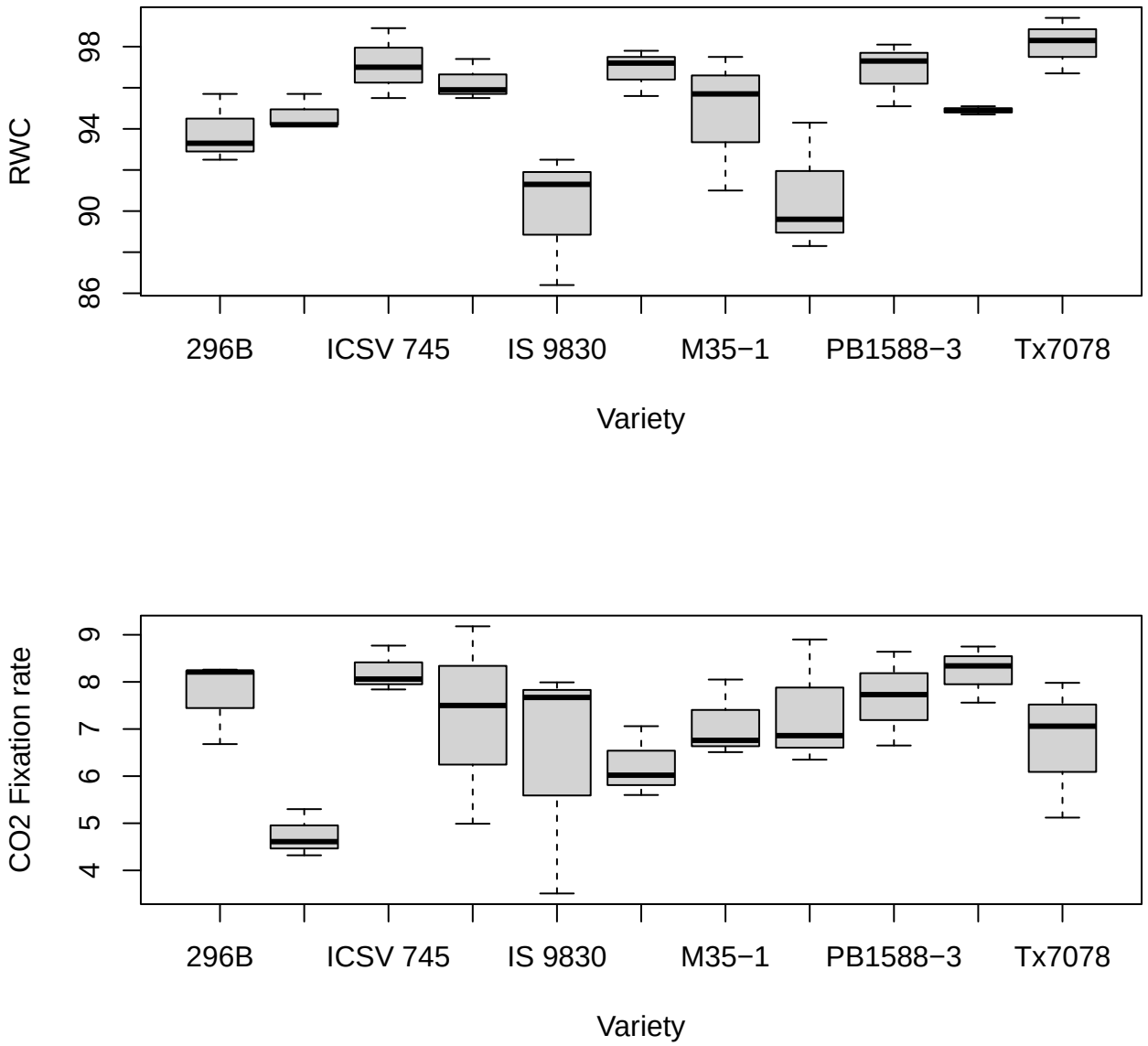

Figure 5: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when PEG conc. is 0.1*

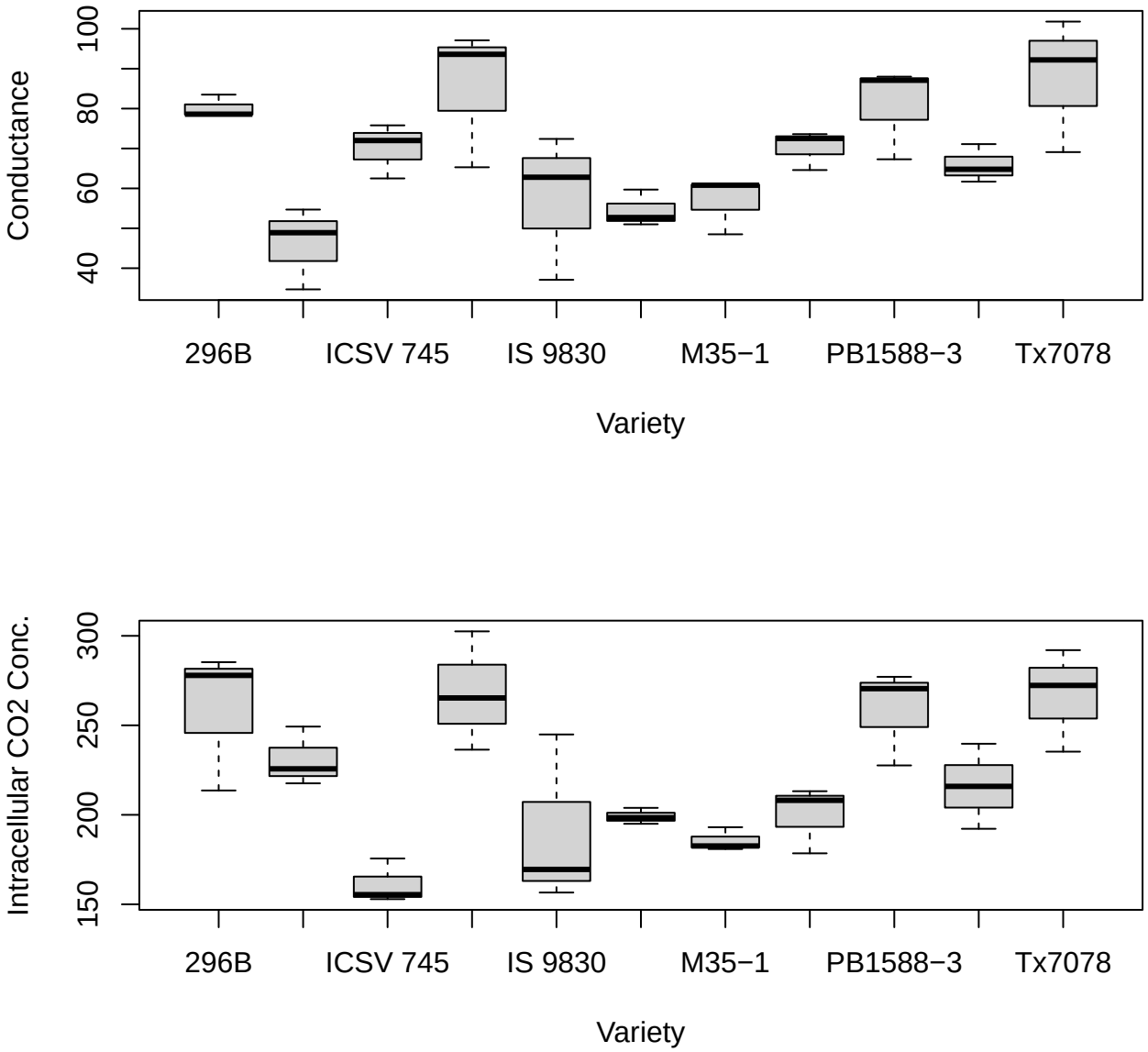

Figure 6: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when PEG conc. is 0.1.*

- **Relative water content**: IS22380, PB1588-3 and Tx7078 are among the varieties with highest relative water content while R16 having the least along with a huge variance in it's observations.
- **CO_2 Fixation rate**: ICSV 745, PB1588-3 and R16 have a higher CO_2 fixation rate with a comparatively less variance than IS 18551 and IS 9830. E36-1 has the lowest CO_2 fixation rate.

(Refer to Figure 6 on the previous page)

1. **Conductance**: IS 18551, Tx7078 and PB1588-3 have a higher level of conductance but the variance in their observations is quite large. E36-1 has the lowest conductance with a comparaively lower variance.
2. **Intracellular CO_2 conc.** : 296B, IS 18551, Tx7078 and PB1588-3 have a comparatively higher level of concentration than the others but again the observations vary a lot among themselves. ICSV 745 has the lowest concentration and the observation variance is also small.

PEG conc. 0.15

Variety	RWC	CO2	Cond	Int
296B : 3	Min. :80.50	Min. :2.630	Min. :32.8	Min. :150.6
E36-1 : 3	1st Qu.:90.40	1st Qu.:5.290	1st Qu.:54.4	1st Qu.:209.6
ICSV 745: 3	Median :93.60	Median :5.990	Median :61.0	Median :225.1
IS 18551: 3	Mean :92.72	Mean :6.062	Mean :64.6	Mean :227.3
IS 9830 : 3	3rd Qu.:95.60	3rd Qu.:7.320	3rd Qu.:77.5	3rd Qu.:258.6
IS22380 : 3	Max. :97.70	Max. :9.270	Max. :99.7	Max. :309.9
(Other) :15				

There is a further increase in the total variation of the relative water content and CO_2 fixation rate while Intracellular CO_2 conc. has a slight decrease in the total variation We create boxplots for further visualisations of the variations.

From the available data, comparisions among the varieties based on the four response variables are done:

(Refer to Figure 7 on the following page)

- **Relative water content**: IS22380, PB1588-3 and ICSV 745 are among the varieties with highest relative water content and a comparitively less variance in it's observations. Tx7078 also has a high relative water content but the variation of the observations is a little large.On the other hand R16 has the least relative water content along with a huge variance in it's observations (since there was presence of missing data, so the variance might be undoubtedly large).
- **CO_2 Fixation rate**: IS 9830 has the highest CO_2 fixation rate along with low variance while IS 22380 has the least. E36-1 has the lowest CO_2 fixation rate. Others have a more or less similar rate except the fact that for R16 and M35-1, the variation of the observations is huge

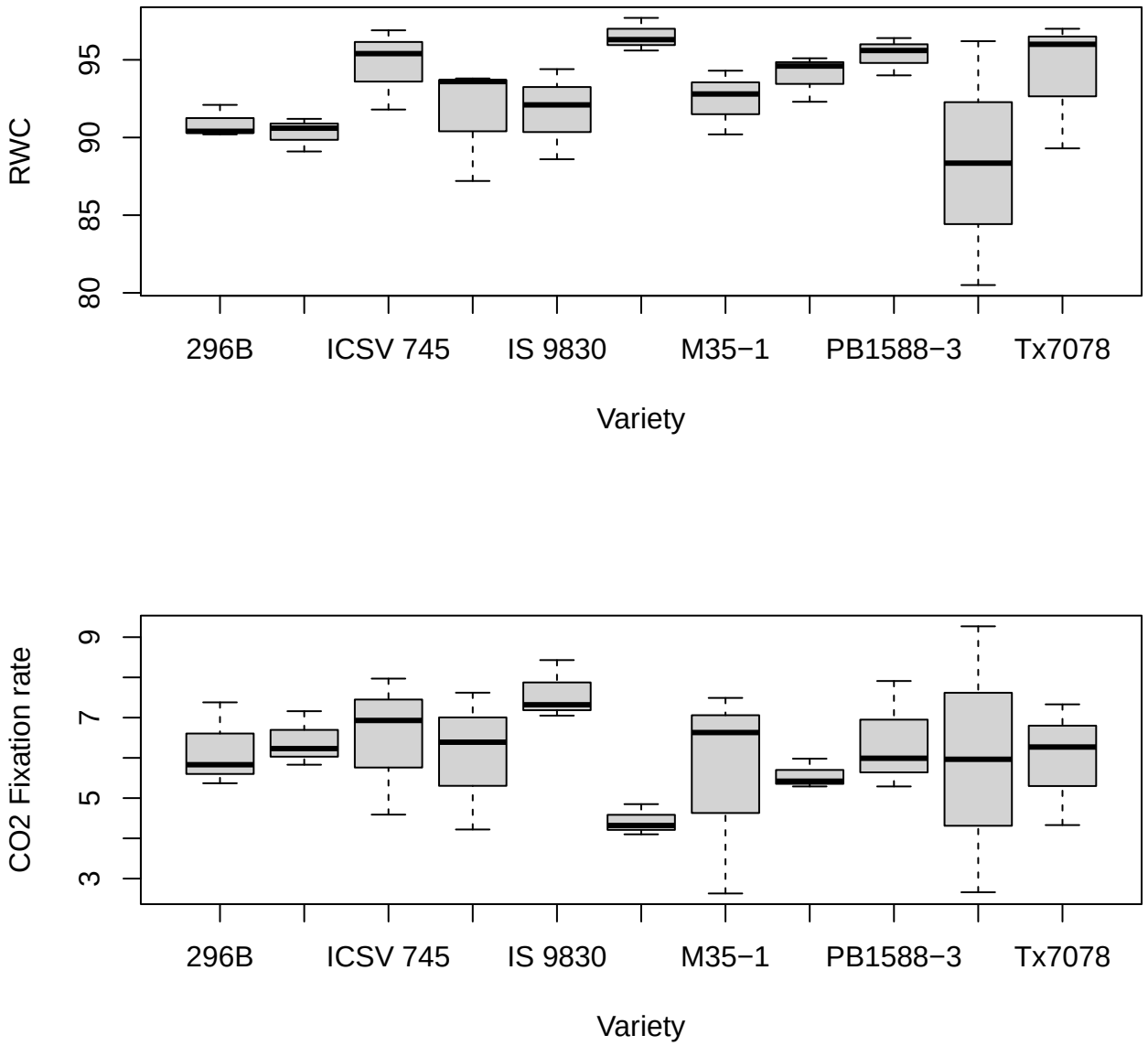

Figure 7: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when PEG conc. is 0.15*

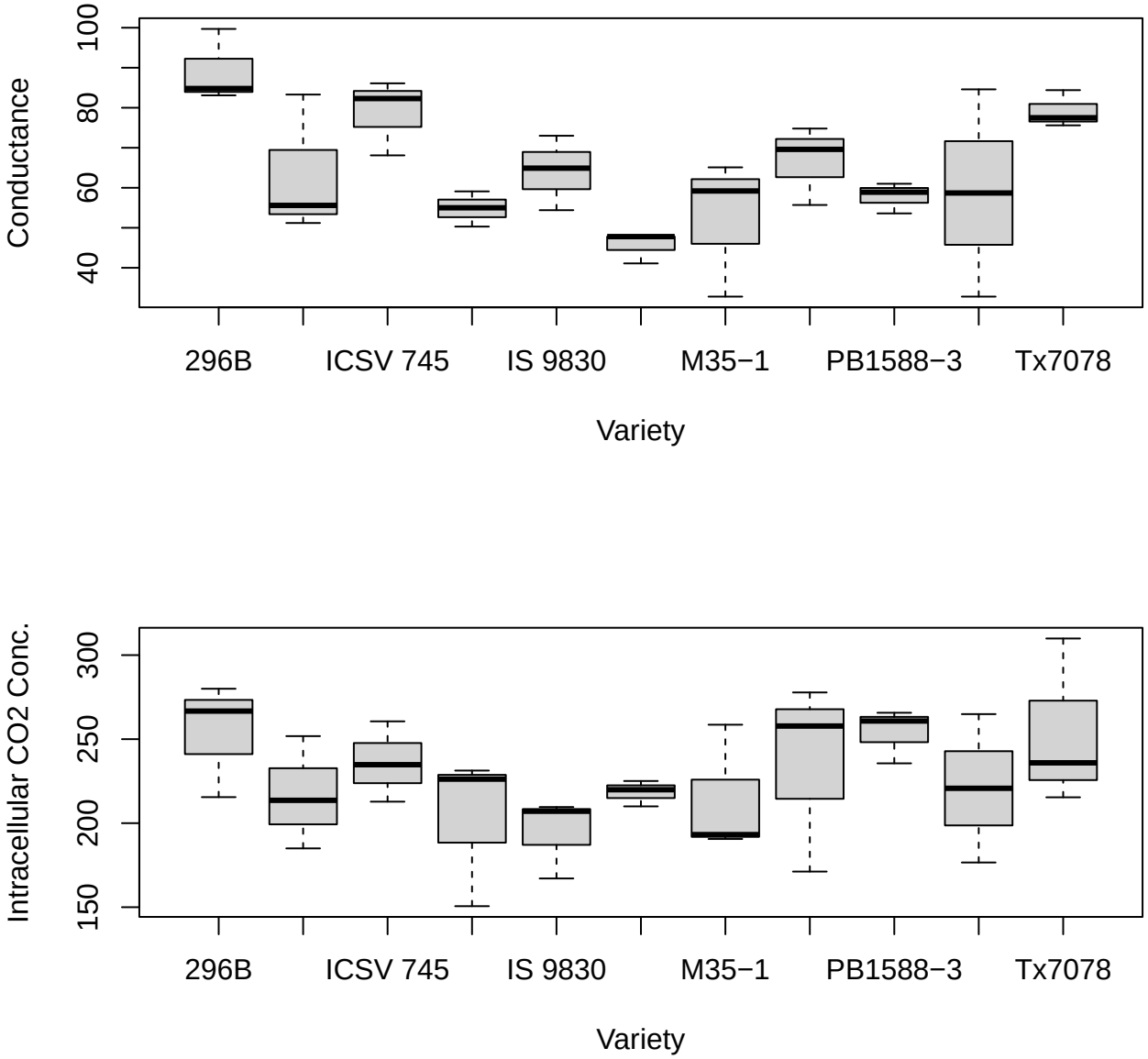

Figure 8: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when PEG conc. is 0.15.*

(Refer to Figure 8 on the previous page)

- **Conductance**: 296B, Tx7078 and ICSV 745 have a higher level of conductance with less variance compared to R16, M35-1 and E36-1. IS22380, IS 18551 and PB1588-3 have low conductance levels.
- **Intracellular CO_2 conc.** : 296B, PB1588-3, N13 have a comparatively higher level of concentration than the others but again the observations vary a lot among themselves.

PEG conc. 0.2

Variety	RWC	CO2	Cond	Int
296B : 3	Min. :56.80	Min. :0.990	Min. :27.00	Min. :111.7
E36-1 : 3	1st Qu.:85.70	1st Qu.:3.730	1st Qu.:39.90	1st Qu.:202.0
ICSV 745: 3	Median :91.70	Median :5.250	Median :49.10	Median :246.9
IS 18551: 3	Mean :87.38	Mean :5.011	Mean :51.12	Mean :249.3
IS 9830 : 3	3rd Qu.:94.40	3rd Qu.:6.230	3rd Qu.:60.30	3rd Qu.:293.5
IS22380 : 3	Max. :98.20	Max. :8.320	Max. :98.90	Max. :405.7
(Other) :15				

An increase in the variation of the four response variables is observed, highlighting a drastic increase in the total variation of relative water content and intracellular CO_2 conc.

From the available data, comparisions among the varieties based on the four response variables are done:

(Refer to Figure 9 on the following page)

- **Relative water content**: ICSV 745, IS 18551, PB1588-3, IS2380 have a high relative water content than others and the variation of the observations is less. The huge within group variation for 296B, E36-1, Tx7078 is the reason for the increase in the total variation of the relative water content.
- **CO_2 Fixation rate**: IS 9830 and PB1588-3 have a higher rate with low within group variance. Tx7078 also has a high rate, but the within group variation makes it a little doubtful.

(Refer to Figure 10 on page 16)

- **Conductance**: PB1588-3 and Tx7078 have a much higher conductance level than others but the variation of the observation is large. E36-1 has the lowest conductance level
- **Intracellular CO_2 conc.** : 296B and R16 have high concentrations but the observations vary a lot from one another whereas PB1588-3 having a high concentration has comparatively low within group variance. IS 9830, M35-1 have a low concentration

PEG conc. 0.25

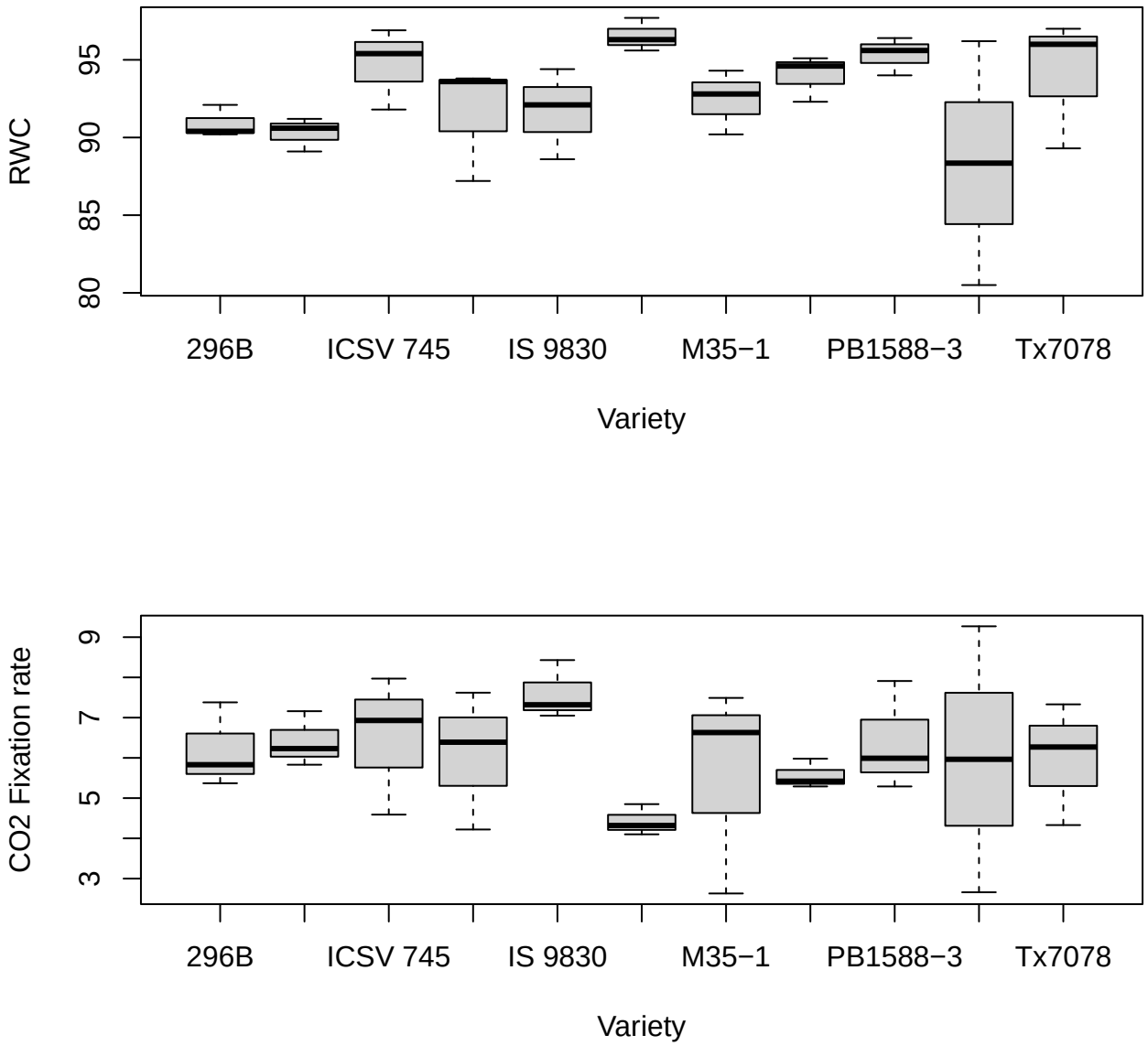

Figure 9: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when PEG conc. is 0.2*

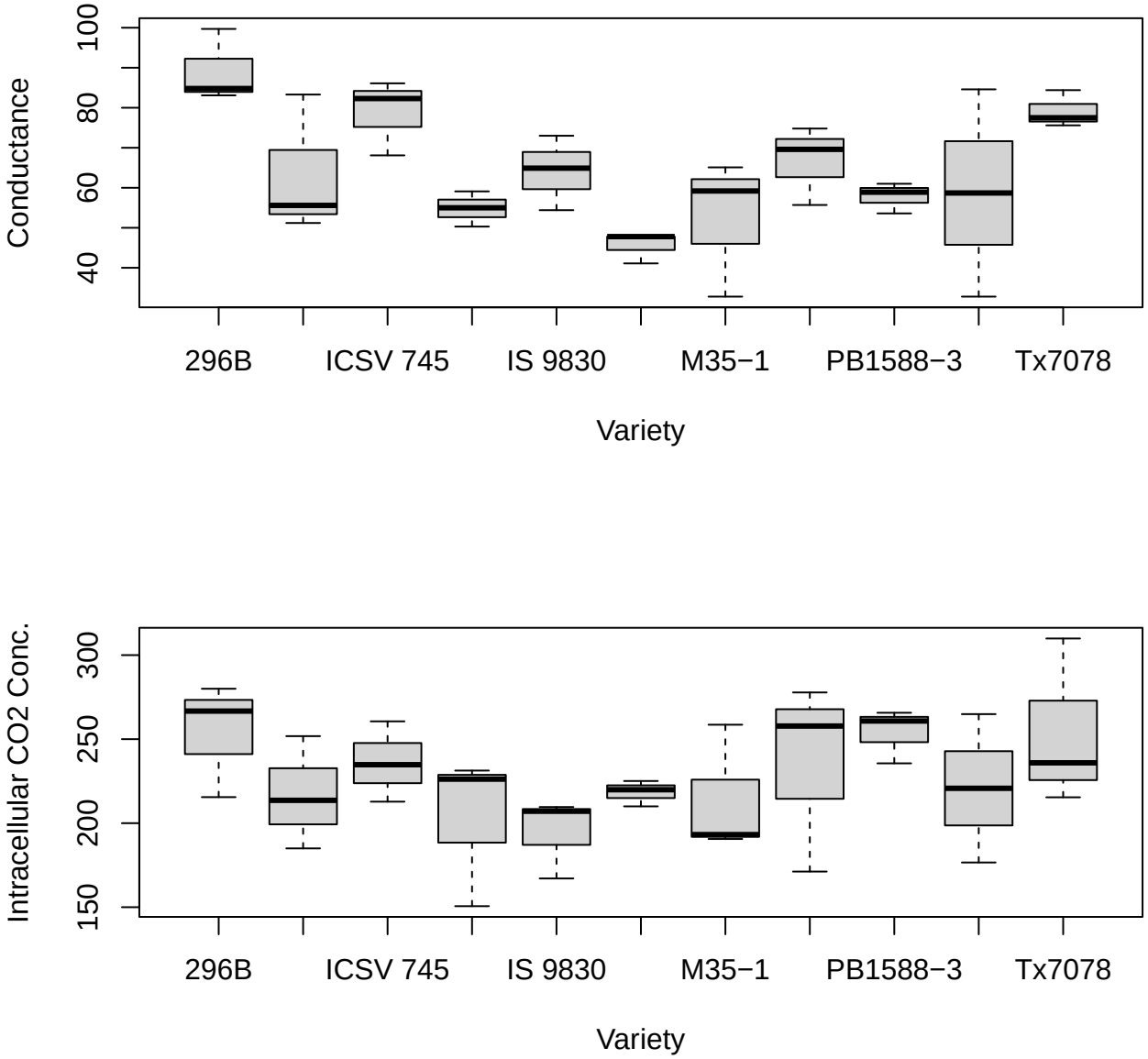

Figure 10: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when PEG conc. is 0.2.*

Variety	RWC	CO2	Cond	Int
296B : 3	Min. :46.90	Min. :1.240	Min. :14.60	Min. :122.9
E36-1 : 3	1st Qu.:64.80	1st Qu.:1.990	1st Qu.:28.80	1st Qu.:229.5
ICSV 745: 3	Median :76.90	Median :3.210	Median :39.50	Median :267.7
IS 18551: 3	Mean :75.91	Mean :3.416	Mean :38.78	Mean :266.8
IS 9830 : 3	3rd Qu.:87.00	3rd Qu.:4.790	3rd Qu.:49.70	3rd Qu.:302.6
IS22380 : 3	Max. :94.90	Max. :6.470	Max. :66.20	Max. :436.3
(Other) :15				

From the above summary , a further increase in the total variation of the relative water content and conductance is observed. The variation of the other two responses are more or less same when compared to PEG conc. 0.2. We create boxplots for further visualisations

From the available data, comparisions among the varieties based on the four response variables are done:

(Refer to Figure 11 on the following page)

- **Relative water content**: PB1588-3, IS 18551, IS22380 and R16 have a relative water content. The within group variation is the least for IS 18551 and PB1588-3, while for others it's a little high. 296B has a very low relative water content
- **CO_2 Fixation rate**: Inspite of huge variations in the observed values in each group, PB1588-3 and IS 18551 have a high rate and 296B and N13 have very low fixation rates

(Refer to Figure 12 on page 19)

- **Conductance**: PB1588-3 has a significantly high conductance level with a high variation though, followed by 296B, IS 18551, R16 and Tx7078. N13 has the lowest conductance level.
- **Intracellular CO_2 conc.** : N13, PB1588-3, 296B and Tx7078 have high concentrations while IS 9830 has the lowest

From the 6 concentration levels, varieties like PB1588-3, IS 18551 tend to survive more in severe drought conditions. Since the observations fluctuate a lot, we proceed towards inferential analysis.

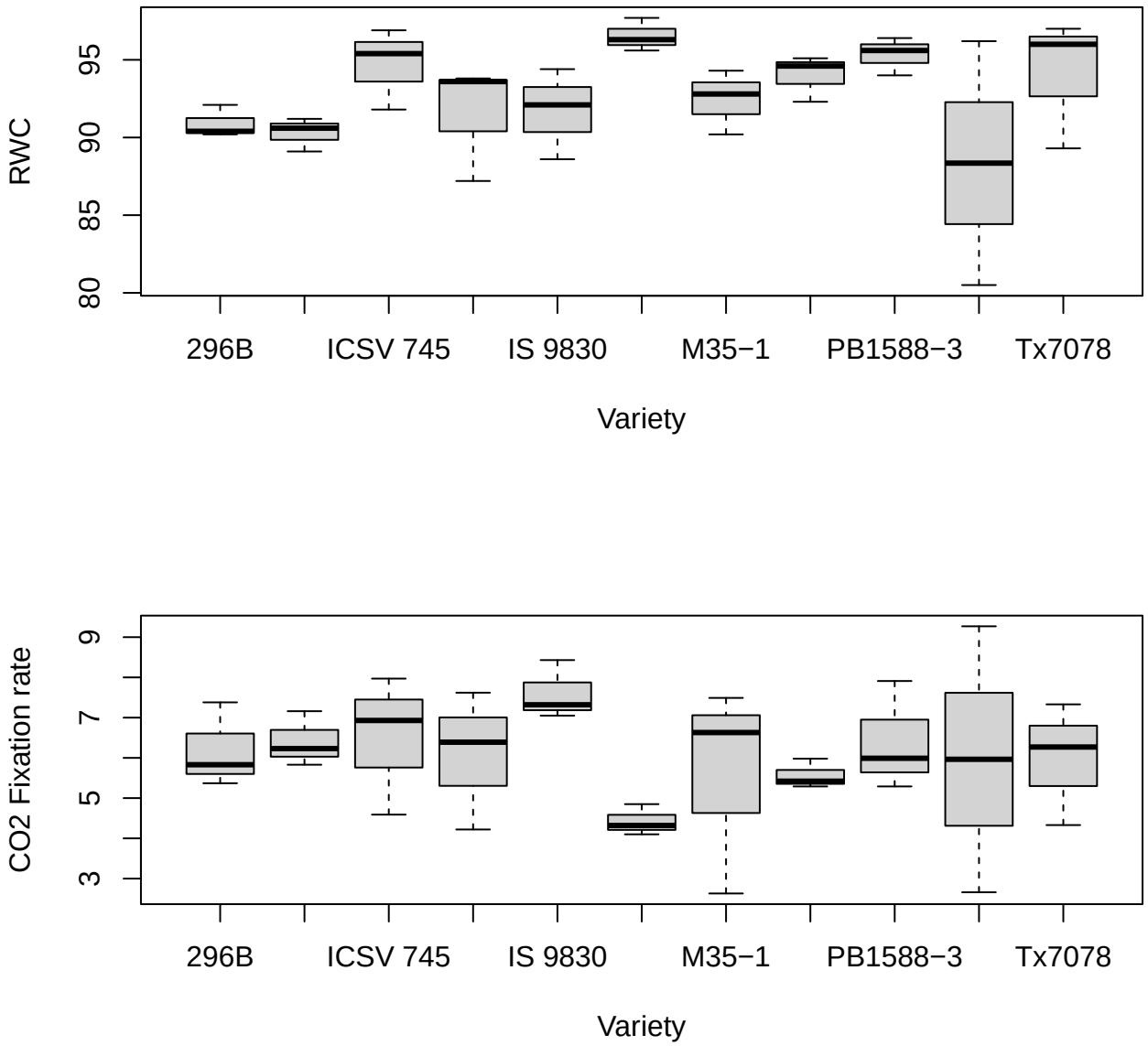

Figure 11: *Boxplots for "Relative water content" and "CO_2 Fixation rate" of the various varieties, when PEG conc. is 0.25*

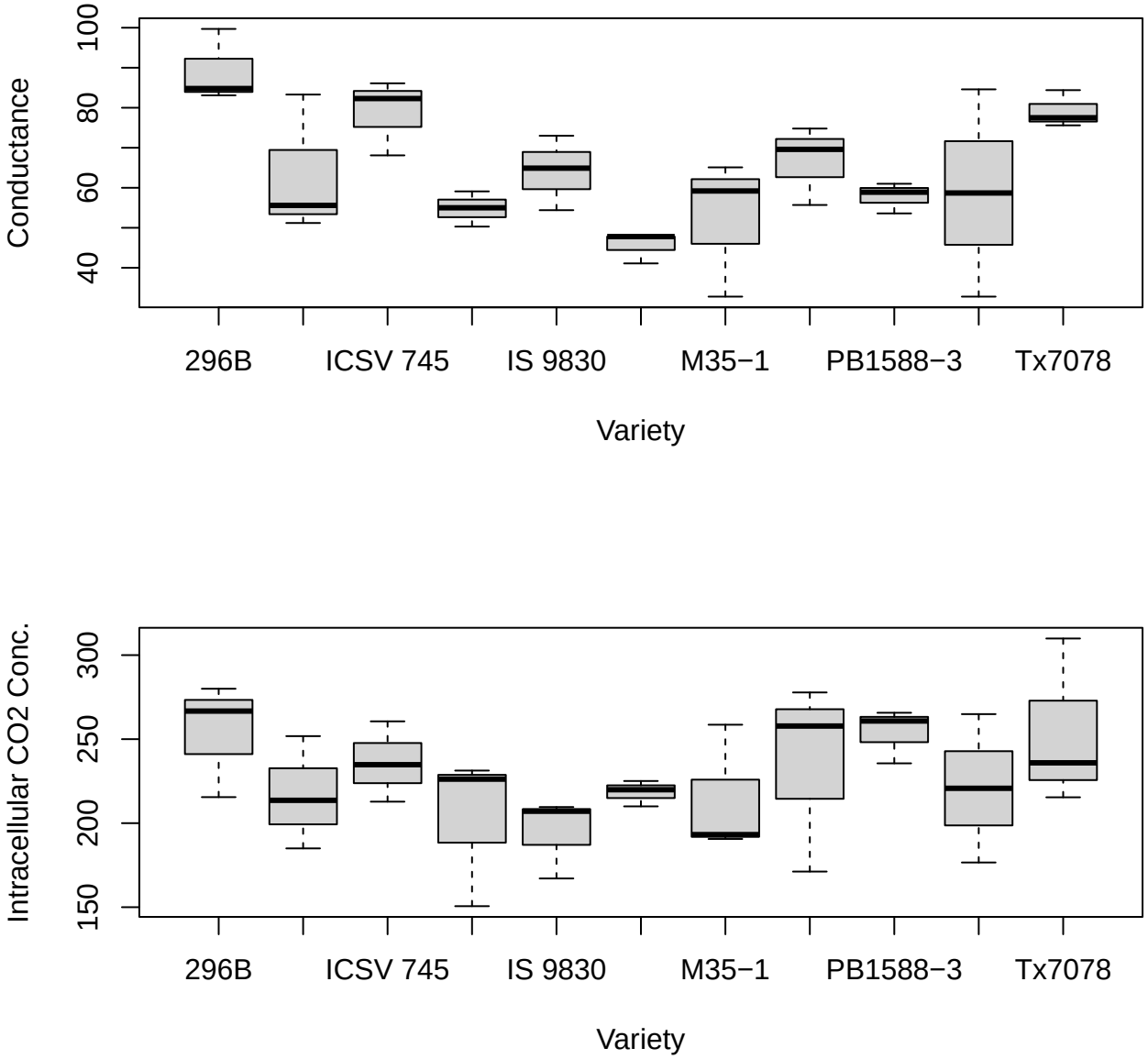

Figure 12: *Boxplots for "Conductance" and "Intracellular CO_2 conc." of the various varieties, when PEG conc. is 0.25.*

Investigation about normality

Before proceeding to the further analysis, normality of the data is checked for each response variable and for each PEG conc.

From the figure 13 on the following page , it is observed that for each and every PEG concentration the "Relative Water Content" observations don't lie exactly along the straight line. Along the tails there is a deviation from normality and the most significant among the deviations is for PEG conc. 0.2. From the figure 14 on page 22, for all the PEG concentrations, the "CO_2 fixation rate"observations are more or less normally distributed. From the figure 15 on page 23, a significant violation of the normality assumption is observed for "Conductance" observations, for concentration level 0 and 0.05 while for other concentration levels the data seems to be nearly normally distributed. Similarly from figure 16 on page 24, a significant violation of normality is observed in the first two PEG concentrations for "Intracellular CO_2 conc." observations while for other concentration levels the data are more or less normally distributed.

Data Modelling:

Our main objectives in this project is to compare the 11 varieties of "Sorghum Bicolor" with respect to the responses measured, at a given value of PEG concentration. So originally there were two factor variables present in our experiment.

1. PEG concentration
2. Varieties

If the PEG concentration is kept fixed, then our model, for each response, would consider a single factor variable i.e. "Varieties" which has 11 levels. So for each response variable, at a given PEG concentration, a single factor ANOVA model will be constructed, so that we can compare the means of each response across the varieties, in order to provide a comparision between the varieties.

One way ANOVA model

Let "Relative Water Content", "CO_2 fixation rate", "Conductance" and "Intracellular CO_2 conc." be denoted by y_1, y_2, y_3 and y_4 respectively. The "Varieties" is considered as a factor variable which has 11 levels. So 10 dummy variables are going to be introduced in our model. For a single factor ANOVA model, following are the assumptions made before building the model.

1. Corresponding to each factor level there is a probability distribution. each probability distribution is normally distributed
2. Each probability distribution has equal variance
3. The responses for each factor level are random selections from the corresponding probability distribution and are independent of responses for any other factor level.

In order to check the validity of these assumptions, following tests are performed

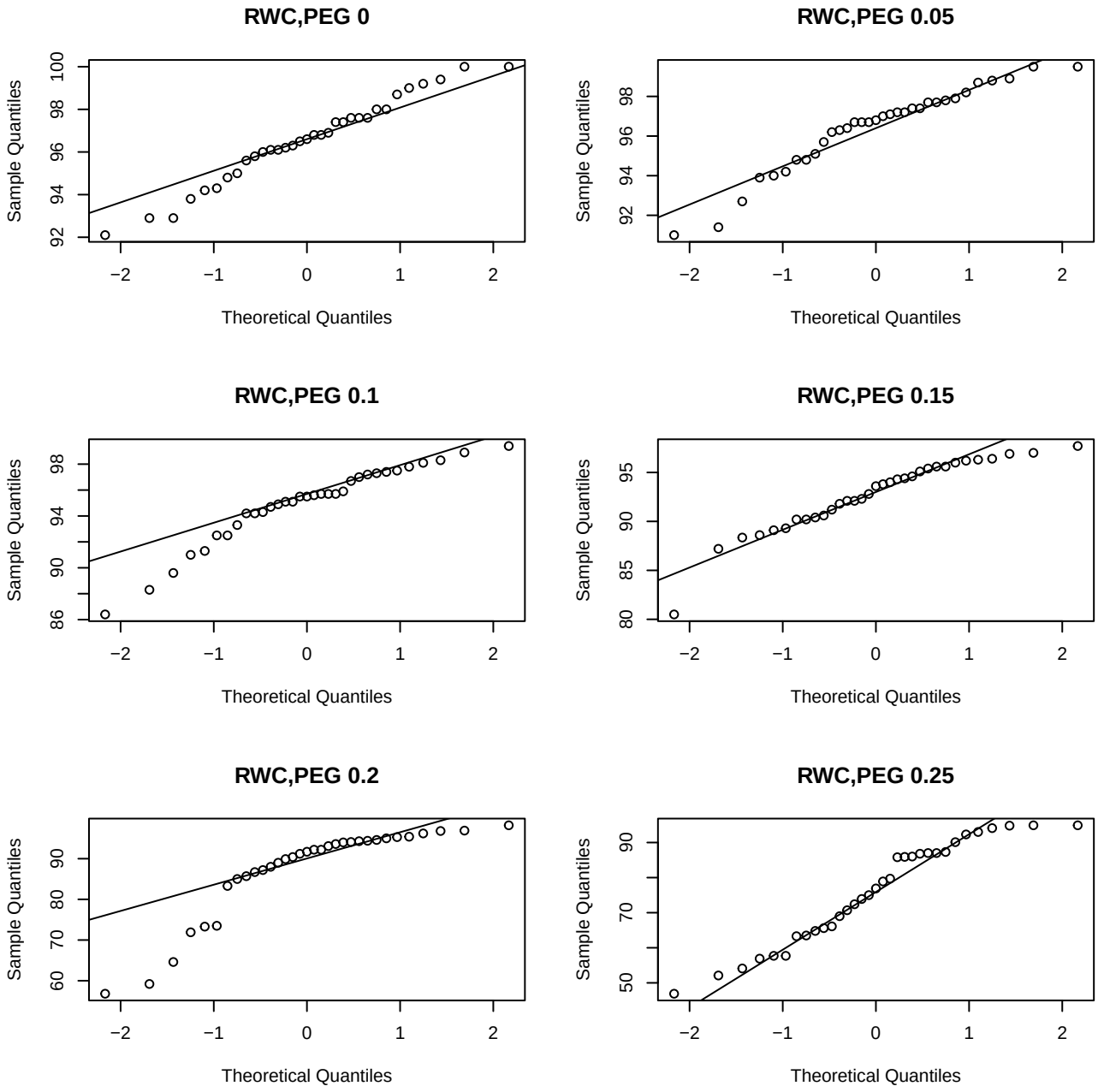

Figure 13: *The Q-Q plots for RWC for the six PEG conc. levels*

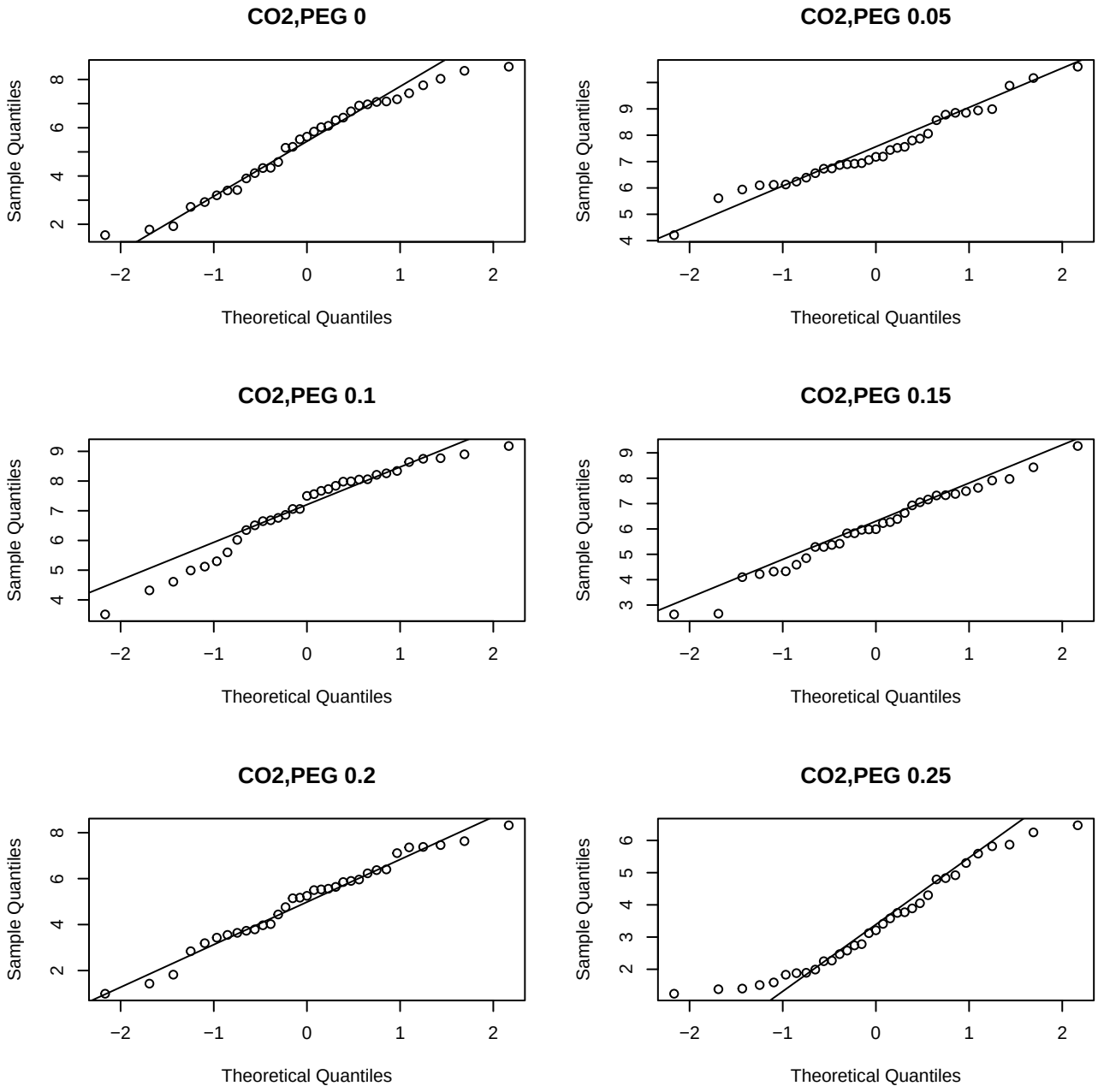

Figure 14: *The Q-Q plots for CO_2 fixation rate for the six PEG conc. levels*

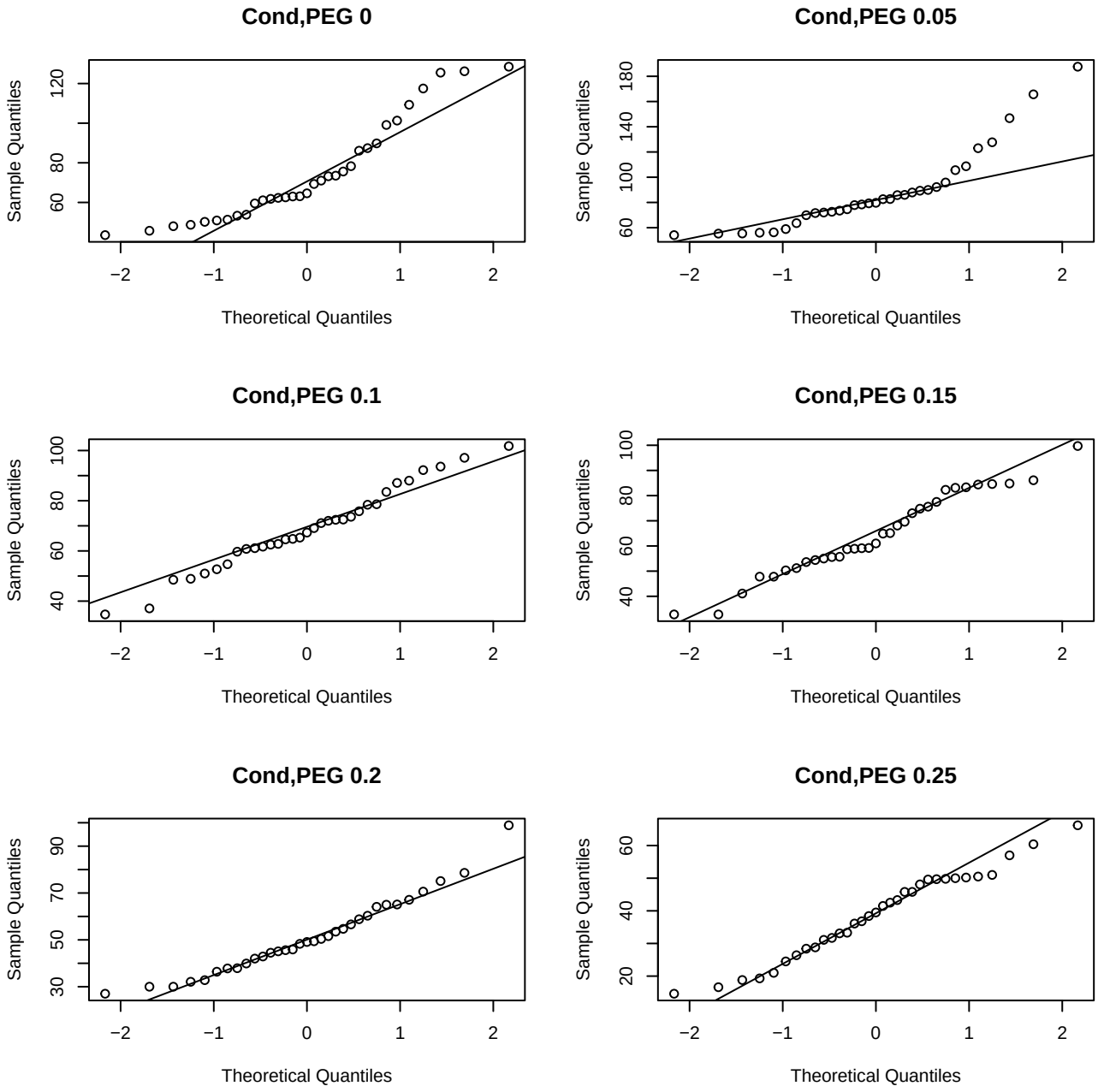

Figure 15: *The Q-Q plots for Conductance for the six PEG conc. levels*

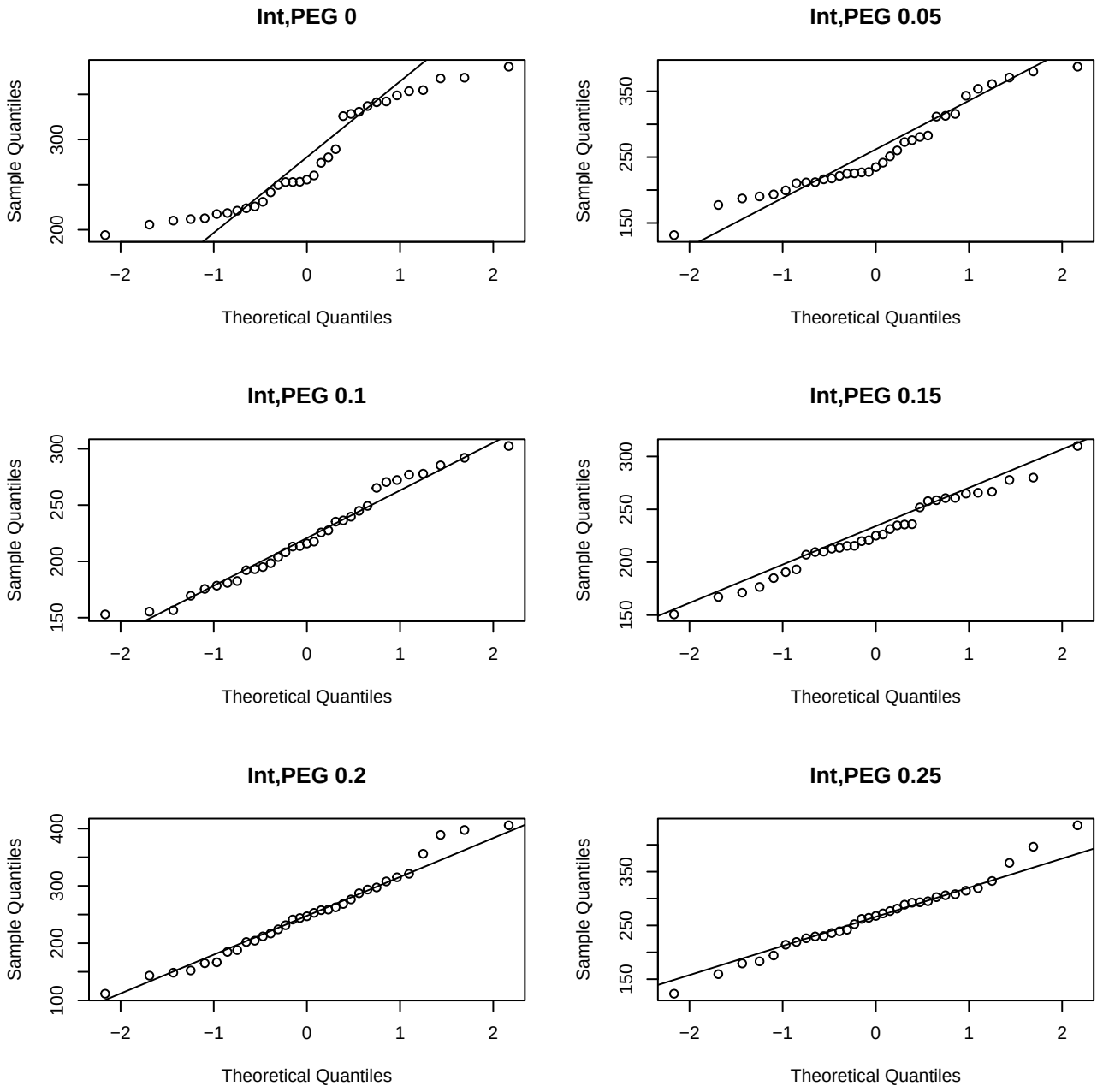

Figure 16: *The Q-Q plots for Conductance for the six PEG conc. levels*

0.1 Variance equality test

Since there are 11 varieties, Bartlett's test will be appropriate for testing the variance. Coming to the statistical hypothesis for Bartlett's test

H_0 : All varieties have equal variance

H_1 : Atleast two of them are different.

For each PEG concentration level and for each response, the Bartlett's test will be performed

0.1.1 PEG conc. 0, RWC

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 4.7802, df = 10, p-value = 0.9054
```

0.1.2 PEG conc. 0, CO_2 fixation rate

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 8.1137, df = 10, p-value = 0.6177
```

0.1.3 PEG conc. 0, Conductance

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 30.651, df = 10, p-value = 0.0006699
```

0.1.4 PEG conc. 0, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 16.246, df = 10, p-value = 0.09281
```

0.1.5 PEG conc. 0.05, RWC.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 15.927, df = 10, p-value = 0.1017
```

0.1.6 PEG conc. 0.05, CO_2 fixation rate.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 14.816, df = 10, p-value = 0.1389
```

0.1.7 PEG conc. 0.05, Conductance.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 27.593, df = 10, p-value = 0.002096
```

0.1.8 PEG conc. 0.05, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 15.088, df = 10, p-value = 0.1289
```

0.1.9 PEG conc. 0.1, RWC.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 13.575, df = 10, p-value = 0.1933
```

0.1.10 PEG conc. 0.1, CO_2 fixation rate.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 10.261, df = 10, p-value = 0.4179
```

0.1.11 PEG conc. 0.1, Conductance.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 11.458, df = 10, p-value = 0.323
```

0.1.12 PEG conc. 0.1, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 12.381, df = 10, p-value = 0.2603
```

0.1.13 PEG conc. 0.15, RWC.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 16.164, df = 10, p-value = 0.09503
```

0.1.14 PEG conc. 0.15, CO_2 fixation rate.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 14.153, df = 10, p-value = 0.1661
```

0.1.15 PEG conc. 0.15, Conductance.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 13.77, df = 10, p-value = 0.1837
```

0.1.16 PEG conc. 0.15, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 7.6595, df = 10, p-value = 0.6621
```

0.1.17 PEG conc. 0.2, RWC.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 27.543, df = 10, p-value = 0.002136
```

0.1.18 PEG conc. 0.2, CO_2 fixation rate.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 15.693, df = 10, p-value = 0.1088
```

0.1.19 PEG conc. 0.2, Conductance.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 7.9995, df = 10, p-value = 0.6289
```

0.1.20 PEG conc. 0.2, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 9.7389, df = 10, p-value = 0.4637
```

0.1.21 PEG conc. 0.25, RWC.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  RWC by Variety
## Bartlett's K-squared = 24.491, df = 10, p-value = 0.0064
```

0.1.22 PEG conc. 0.25, CO_2 fixation rate.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  CO2 by Variety
## Bartlett's K-squared = 10.276, df = 10, p-value = 0.4166
```

0.1.23 PEG conc. 0.25, Conductance.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Cond by Variety
## Bartlett's K-squared = 7.1582, df = 10, p-value = 0.7104
```

0.1.24 PEG conc. 0.25, Intracellular CO_2 conc.

```
##
##  Bartlett test of homogeneity of variances
##
## data:  Int by Variety
## Bartlett's K-squared = 11.702, df = 10, p-value = 0.3055
```

Conclusion: Apart from (PEG conc. 0, Conductance),(PEG conc. 0.05, Conductance),(PEG conc. 0.2, RWC), (PEG conc. 0.25, RWC), others don't have a significant difference in variance

0.2 Normality check

To further investigate about the normality of our data, Shapiro Wilk's test is performed. Coming to the statistical hypothesis for Shapiro Wilk's test

H_0 : The data is normally distributed

H_1 : The data is not normally distributed.

0.2.1 PEG conc. 0, RWC

```
##
##  Shapiro-Wilk normality test
##
## data:  P0$RWC
## W = 0.9749, p-value = 0.626
```

0.2.2 PEG conc. 0, CO_2 fixation rate

```
##
##  Shapiro-Wilk normality test
##
## data:  P0$CO2
## W = 0.96045, p-value = 0.2661
```

0.2.3 PEG conc. 0, Conductance

```
##
##  Shapiro-Wilk normality test
##
## data:  P0$Cond
## W = 0.88882, p-value = 0.002766
```

0.2.4 PEG conc. 0, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0$Int
## W = 0.89967, p-value = 0.005222
```

0.2.5 PEG conc. 0.05, RWC.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.05$RWC
## W = 0.92923, p-value = 0.03328
```

0.2.6 PEG conc. 0.05, CO_2 fixation rate.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.05$CO2
## W = 0.96872, p-value = 0.4458
```

0.2.7 PEG conc. 0.05, Conductance.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.05$Cond
## W = 0.83561, p-value = 0.0001668
```

0.2.8 PEG conc. 0.05, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.05$Int
## W = 0.93904, p-value = 0.0637
```

0.2.9 PEG conc. 0.1, RWC.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.1$RWC
## W = 0.92284, p-value = 0.02197
```

0.2.10 PEG conc. 0.1, CO_2 fixation rate.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.1$CO2
## W = 0.94264, p-value = 0.08106
```

0.2.11 PEG conc. 0.1, Conductance.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.1$Cond
## W = 0.9838, p-value = 0.891
```

0.2.12 PEG conc. 0.1, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.1$Int
## W = 0.96429, p-value = 0.3402
```

0.2.13 PEG conc. 0.15, RWC.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.15$RWC
## W = 0.91297, p-value = 0.01176
```

0.2.14 PEG conc. 0.15, CO_2 fixation rate.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.15$CO2
## W = 0.98027, p-value = 0.7944
```

0.2.15 PEG conc. 0.15, Conductance.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.15$Cond
## W = 0.96974, p-value = 0.4731
```

0.2.16 PEG conc. 0.15, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.15$Int
## W = 0.98385, p-value = 0.8923
```

0.2.17 PEG conc. 0.2, RWC.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.2$RWC
## W = 0.78198, p-value = 1.49e-05
```

0.2.18 PEG conc. 0.2, CO_2 fixation rate.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.2$CO2
## W = 0.9743, p-value = 0.6073
```

0.2.19 PEG conc. 0.2, Conductance.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.2$Cond
## W = 0.95252, p-value = 0.1576
```

0.2.20 PEG conc. 0.2, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.2$Int
## W = 0.975, p-value = 0.629
```

0.2.21 PEG conc. 0.25, RWC.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.25$RWC
## W = 0.93433, p-value = 0.04657
```

0.2.22 PEG conc. 0.25, CO_2 fixation rate.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.25$CO2
## W = 0.93893, p-value = 0.06324
```

0.2.23 PEG conc. 0.25, Conductance.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.25$Cond
## W = 0.97222, p-value = 0.5439
```

0.2.24 PEG conc. 0.25, Intracellular CO_2 conc.

```
##
##  Shapiro-Wilk normality test
##
## data:  P0.25$Int
## W = 0.98288, p-value = 0.868
```

Conclusion: (PEG conc. 0, Conductance), (PEG conc. 0, Intracellular CO_2 conc.),(PEG conc. 0.05, RWC), (PEG conc. 0.05, Conductance),(PEG conc. 0.1, RWC), (PEG conc. 0.15, RWC), (PEG conc. 0.2, RWC), (PEG conc. 0.25, RWC) violate the normality assumption as their p-value is less than the significance level 0.05

Solution to the violation of assumptions

Since violation of the assumptions are detected for our observations, a non parametric test viz. Kruskal Wallis test is going to be performed, which does require the assumption of normality of the data nor homoscedascticity of the data. The only assumptions for this test are:

1. The samples are mutually independent
2. They belong to a continuous distribution
3. The distribution functions $F_1, ..., F_{11}$ (as there are only 11 varieties) are connected through the relatioship $F_i(t) = F(t - \theta_i),\ i = 1(1)11$ where F is a DF for a continuous distributions with unknown median θ and θ_i is the unknown effect for the i^{th} population.

Responses for which all the assumptions are satisfied, the analysis will be proceeded using ANOVA.

Building the model for ANOVA

The varieties of 'Sorghum Bicolor' is a factor which constitutes the population of interest. Further there are three observations for each level of the factor and let y_{kij} be the j^{th} observation of the i^{th} level of the factor and $k = 1, 2, 3, 4$ which varies depending on which response variable is been taken. The model considered is

$$y_{kij} = \mu_k + \alpha_{ki} + e_{kij} \qquad j = 1(1)3, i = 1(1)11, k = 1(1)4$$

where μ_k denoted the general effect or the average effect and α_{ki} denoted the additional effect (fixed) due to i^{th} level of the factor, subject to the restriction that $3\sum_i \alpha_{ki} = 0$ and e_{kij} denotes the random error.

Hypothesis of interest

For ANOVA:

It is of our interest to test
$H_0 : \alpha_{k1} = \alpha_{k2} = ... = \alpha_{k11}$
against
H_1 : not H_0 (That is atleast one inequality in H_0)

This means that whether the effects of all varieties are same or not, is being tested.

For Kruskal Wallis test:

It is of our interest to test
$H_0 : \theta_1 = \theta_2 = ... = \theta_{11}$
against
H_1 : not H_0 (That is $\theta_i \neq \theta_{i'}$ for atleast one $i \neq i'$)

which means whether the effects of all the varieties are same or not

Testing (ANOVA)

PEG 0, RWC

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  72.27   7.227   2.698 0.0251 *
## Residuals   22  58.93   2.678
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Variety     10  114.9  11.492   22.18 3.12e-09 ***
## Residuals   22   11.4   0.518
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.05, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  26.45   2.645     1.6  0.172
## Residuals   22  36.37   1.653
```

PEG 0.05, Intracellular CO_2 conc.

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Variety     10 109801   10980   8.543 1.58e-05 ***
## Residuals   22  28276    1285
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.1, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  30.75   3.075   1.824  0.115
## Residuals   22  37.09   1.686
```

PEG 0.1, Conductance

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     10   5729   572.9   4.711 0.00118 **
## Residuals   22   2675   121.6
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.1, Intracellular CO_2 conc.

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Variety     10  41801    4180   5.832 0.000281 ***
## Residuals   22  15768     717
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.15, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  17.95   1.795   0.655  0.753
## Residuals   22  60.31   2.742
```

PEG 0.15, Conductance

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     10   5144   514.4   3.333 0.00887 **
## Residuals   22   3395   154.3
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.15, Intracellular CO_2 conc.

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  13071    1307   0.965  0.499
## Residuals   22  29803    1355
```

PEG 0.2, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  39.71   3.971   1.287  0.297
## Residuals   22  67.90   3.086
```

PEG 0.2, Conductance

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     10   5289   528.9   4.043 0.00301 **
## Residuals   22   2878   130.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.2, Intracellular CO_2 conc.

```
##             Df Sum Sq Mean Sq F value   Pr(>F)
## Variety     10 121520   12152   4.843 0.000985 ***
## Residuals   22  55202    2509
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.25, CO_2 Fixation rate

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## Variety     10  30.01   3.001    1.33  0.276
## Residuals   22  49.65   2.257
```

PEG 0.25, Conductance

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     10   3447   344.7   3.526 0.00656 **
## Residuals   22   2151    97.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

PEG 0.25, Intracellular CO_2 conc.

```
##             Df Sum Sq Mean Sq F value  Pr(>F)
## Variety     10  87237    8724   3.895 0.00375 **
## Residuals   22  49275    2240
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusion:

It is observed that that the null hypothesis is rejected at 0.05 level of significance for (PEG 0, RWC), (PEG 0, CO_2 fixation rate), (PEG 0.05, Intracellular CO_2 conc.), (PEG 0.1, Conductance), (PEG 0.1, Intracellular CO_2 conc.), (PEG 0.15, Conductance), (PEG 0.2, Conductance), (PEG 0.2, Intracellular CO_2 conc.), (PEG 0.25, Conductance), (PEG 0.25, Intracellular CO_2 conc.).

Since the null hypothesis got rejected, pairwise comparision is done for further comparision.

Testing (Kruskal Wallis Test)

PEG 0, Conductance

```
##
##  Kruskal-Wallis rank sum test
##
## data:  Cond by Variety
## Kruskal-Wallis chi-squared = 26.439, df = 10, p-value = 0.003193
```

PEG 0, Intracellular CO_2 conc.

```
##
##  Kruskal-Wallis rank sum test
##
## data:  Int by Variety
## Kruskal-Wallis chi-squared = 27.334, df = 10, p-value = 0.002305
```

PEG 0.05, RWC

```
##
##  Kruskal-Wallis rank sum test
##
## data:  RWC by Variety
## Kruskal-Wallis chi-squared = 22.126, df = 10, p-value = 0.01448
```

PEG 0.05, Conductance

```
##
##  Kruskal-Wallis rank sum test
##
## data:  Cond by Variety
## Kruskal-Wallis chi-squared = 23.636, df = 10, p-value = 0.008626
```

PEG 0.1, RWC

```
##
##  Kruskal-Wallis rank sum test
##
## data:  RWC by Variety
## Kruskal-Wallis chi-squared = 21.585, df = 10, p-value = 0.01736
```

PEG 0.15, RWC

```
##
##  Kruskal-Wallis rank sum test
##
## data:  RWC by Variety
## Kruskal-Wallis chi-squared = 15.17, df = 10, p-value = 0.126
```

PEG 0.2, RWC

```
##
##  Kruskal-Wallis rank sum test
##
## data:  RWC by Variety
## Kruskal-Wallis chi-squared = 16.286, df = 10, p-value = 0.09173
```

PEG 0.25, RWC

```
##
##  Kruskal-Wallis rank sum test
##
## data:  RWC by Variety
## Kruskal-Wallis chi-squared = 18.153, df = 10, p-value = 0.05243
```

Conclusion

It is observed that that the null hypothesis is rejected at 0.05 level of significance for (PEG 0, Cond), (PEG 0, Intracellular CO_2 conc.), (PEG 0.05, RWC), (PEG 0.05, Conductance) and (PEG 0.1, RWC).

For further investigation pairwise comparision is done for those data for which the null hypothesis got rejected in both ANOVA and Kruskal Wallis test.

Pairwise comparision

Below printed are the pairs of varieties for which the certain response (RWC, Conductance, CO_2 fixation rate and Intracellular CO_2 conc.) is significantly different from each other.

PEG 0, RWC

```
##  [1] "IS 18551, 296B"     "N13, 296B"          "PB1588-3, 296B"
##  [4] "R 16, 296B"         "Tx7078, 296B"       "IS 18551, ICSV 745"
##  [7] "N13, ICSV 745"      "R 16, ICSV 745"     "Tx7078, ICSV 745"
## [10] "N13, IS 9830"       "Tx7078, IS 9830"    "Tx7078, M35-1"
```

PEG 0, CO_2 fixation rate

```
##  [1] "E36-1, 296B"        "IS 18551, 296B"     "IS22380, 296B"
##  [4] "M35-1, 296B"        "PB1588-3, 296B"     "Tx7078, 296B"
##  [7] "ICSV 745, E36-1"    "IS 18551, E36-1"    "IS 9830, E36-1"
## [10] "IS22380, E36-1"     "M35-1, E36-1"       "N13, E36-1"
## [13] "PB1588-3, E36-1"    "R 16, E36-1"        "IS 18551, ICSV 745"
## [16] "IS 9830, ICSV 745"  "IS22380, ICSV 745"  "M35-1, ICSV 745"
## [19] "Tx7078, ICSV 745"   "IS 9830, IS 18551"  "IS22380, IS 18551"
## [22] "M35-1, IS 18551"    "N13, IS 18551"      "PB1588-3, IS 18551"
## [25] "R 16, IS 18551"     "Tx7078, IS 18551"   "M35-1, IS 9830"
## [28] "N13, IS 9830"       "PB1588-3, IS 9830"  "R 16, IS 9830"
## [31] "Tx7078, IS 9830"    "N13, IS22380"       "PB1588-3, IS22380"
## [34] "R 16, IS22380"      "N13, M35-1"         "PB1588-3, M35-1"
## [37] "R 16, M35-1"        "Tx7078, N13"        "Tx7078, PB1588-3"
## [40] "Tx7078, R 16"
```

PEG 0, Conductance

```
##  [1] "296B , IS 18551"     "296B , IS22380"      "296B , M35-1"
##  [4] "E36-1 , IS 18551"    "E36-1 , IS22380"     "E36-1 , M35-1"
##  [7] "E36-1 , R 16"        "ICSV 745 , IS 18551" "ICSV 745 , IS 9830"
## [10] "ICSV 745 , IS22380"  "ICSV 745 , M35-1"    "ICSV 745 , R 16"
## [13] "IS 18551 , IS 9830"  "IS 18551 , IS22380"  "IS 18551 , M35-1"
## [16] "IS 18551 , N13"      "IS 18551 , PB1588-3" "IS 18551 , R 16"
## [19] "IS 18551 , Tx7078"   "IS 9830 , IS22380"   "IS 9830 , M35-1"
## [22] "IS 9830 , PB1588-3"  "IS 9830 , R 16"      "IS 9830 , Tx7078"
## [25] "IS22380 , N13"       "IS22380 , PB1588-3"  "IS22380 , R 16"
## [28] "IS22380 , Tx7078"    "M35-1 , N13"         "M35-1 , PB1588-3"
## [31] "M35-1 , R 16"        "M35-1 , Tx7078"      "N13 , R 16"
## [34] "PB1588-3 , Tx7078"   "R 16 , Tx7078"
```

PEG 0, Intracellular CO_2 fixation

```
##  [1] "296B , E36-1"        "296B , IS 18551"     "296B , IS 9830"
##  [4] "296B , PB1588-3"     "296B , Tx7078"       "E36-1 , ICSV 745"
##  [7] "E36-1 , IS 9830"     "E36-1 , IS22380"     "E36-1 , M35-1"
## [10] "E36-1 , N13"         "E36-1 , R 16"        "ICSV 745 , IS 18551"
## [13] "ICSV 745 , N13"      "ICSV 745 , PB1588-3" "ICSV 745 , Tx7078"
## [16] "IS 18551 , IS 9830"  "IS 18551 , IS22380"  "IS 18551 , M35-1"
## [19] "IS 18551 , N13"      "IS 18551 , PB1588-3" "IS 18551 , R 16"
## [22] "IS 9830 , IS22380"   "IS 9830 , N13"       "IS 9830 , PB1588-3"
## [25] "IS 9830 , R 16"      "IS 9830 , Tx7078"    "IS22380 , PB1588-3"
## [28] "IS22380 , Tx7078"    "M35-1 , PB1588-3"    "M35-1 , Tx7078"
## [31] "N13 , PB1588-3"      "N13 , Tx7078"        "PB1588-3 , R 16"
## [34] "R 16 , Tx7078"
```

PEG 0.05, RWC

```
##  [1] "296B , E36-1"      "296B , IS 18551"   "296B , IS22380"
##  [4] "296B , M35-1"      "296B , R 16"       "296B , Tx7078"
##  [7] "E36-1 , IS 9830"   "E36-1 , N13"       "E36-1 , PB1588-3"
## [10] "E36-1 , R 16"      "E36-1 , Tx7078"    "IS 9830 , M35-1"
## [13] "IS 9830 , Tx7078"  "IS22380 , Tx7078"  "M35-1 , N13"
## [16] "M35-1 , PB1588-3"  "M35-1 , R 16"      "N13 , Tx7078"
## [19] "PB1588-3 , Tx7078" "R 16 , Tx7078"
```

PEG 0.05, Conductance

```
##  [1] "296B , E36-1"        "296B , ICSV 745"     "296B , IS 9830"
##  [4] "296B , IS22380"      "296B , M35-1"        "296B , PB1588-3"
##  [7] "E36-1 , IS 18551"    "E36-1 , IS22380"     "E36-1 , R 16"
## [10] "E36-1 , Tx7078"      "ICSV 745 , IS 18551" "ICSV 745 , IS22380"
## [13] "ICSV 745 , R 16"     "IS 18551 , IS 9830"  "IS 18551 , IS22380"
## [16] "IS 18551 , M35-1"    "IS 18551 , N13"      "IS 18551 , PB1588-3"
## [19] "IS 18551 , R 16"     "IS 18551 , Tx7078"   "IS 9830 , IS22380"
## [22] "IS 9830 , R 16"      "IS 9830 , Tx7078"    "IS22380 , M35-1"
## [25] "IS22380 , PB1588-3"  "IS22380 , R 16"      "IS22380 , Tx7078"
## [28] "M35-1 , R 16"        "PB1588-3 , R 16"     "PB1588-3 , Tx7078"
```

PEG 0.05, Intracellular CO_2 fixation

```
##  [1] "E36-1, 296B"        "ICSV 745, 296B"     "IS 18551, 296B"
##  [4] "IS 9830, 296B"      "IS22380, 296B"      "M35-1, 296B"
##  [7] "N13, 296B"          "R 16, 296B"         "ICSV 745, E36-1"
```

```
## [10] "PB1588-3, E36-1"    "Tx7078, E36-1"      "PB1588-3, ICSV 745"
## [13] "R 16, ICSV 745"     "Tx7078, ICSV 745"   "PB1588-3, IS 18551"
## [16] "Tx7078, IS 18551"   "PB1588-3, IS 9830"  "Tx7078, IS 9830"
## [19] "PB1588-3, IS22380"  "Tx7078, IS22380"    "PB1588-3, M35-1"
## [22] "Tx7078, M35-1"      "PB1588-3, N13"      "R 16, N13"
## [25] "Tx7078, N13"        "R 16, PB1588-3"     "Tx7078, R 16"
```

PEG 0.1, RWC

```
##  [1] "296B , Tx7078"      "E36-1 , IS 9830"    "E36-1 , Tx7078"
##  [4] "ICSV 745 , IS 9830" "ICSV 745 , N13"     "ICSV 745 , R 16"
##  [7] "IS 18551 , IS 9830" "IS 18551 , N13"     "IS 18551 , R 16"
## [10] "IS 9830 , IS22380"  "IS 9830 , PB1588-3" "IS 9830 , R 16"
## [13] "IS 9830 , Tx7078"   "IS22380 , N13"      "IS22380 , R 16"
## [16] "N13 , PB1588-3"     "N13 , R 16"         "N13 , Tx7078"
## [19] "R 16 , Tx7078"
```

PEG 0.1, Conductance

```
##  [1] "E36-1, 296B"       "IS 9830, 296B"     "IS22380, 296B"
##  [4] "M35-1, 296B"       "ICSV 745, E36-1"   "IS 18551, E36-1"
##  [7] "N13, E36-1"        "PB1588-3, E36-1"   "R 16, E36-1"
## [10] "Tx7078, E36-1"     "IS 9830, IS 18551" "IS22380, IS 18551"
## [13] "M35-1, IS 18551"   "R 16, IS 18551"    "PB1588-3, IS 9830"
## [16] "Tx7078, IS 9830"   "PB1588-3, IS22380" "Tx7078, IS22380"
## [19] "PB1588-3, M35-1"   "Tx7078, M35-1"     "Tx7078, R 16"
```

PEG 0.1, Intracellular CO_2 fixation

```
##  [1] "ICSV 745, 296B"     "IS 9830, 296B"      "IS22380, 296B"
##  [4] "M35-1, 296B"        "N13, 296B"          "ICSV 745, E36-1"
##  [7] "M35-1, E36-1"       "IS 18551, ICSV 745" "PB1588-3, ICSV 745"
## [10] "R 16, ICSV 745"     "Tx7078, ICSV 745"   "IS 9830, IS 18551"
## [13] "IS22380, IS 18551"  "M35-1, IS 18551"    "N13, IS 18551"
## [16] "R 16, IS 18551"     "PB1588-3, IS 9830"  "Tx7078, IS 9830"
## [19] "PB1588-3, IS22380"  "Tx7078, IS22380"    "PB1588-3, M35-1"
## [22] "Tx7078, M35-1"      "PB1588-3, N13"      "Tx7078, N13"
## [25] "Tx7078, R 16"
```

PEG 0.15, Conductance

```
##  [1] "E36-1, 296B"        "IS 18551, 296B"     "IS 9830, 296B"
##  [4] "IS22380, 296B"      "M35-1, 296B"        "N13, 296B"
##  [7] "PB1588-3, 296B"     "R 16, 296B"         "IS 18551, ICSV 745"
## [10] "IS22380, ICSV 745"  "M35-1, ICSV 745"    "Tx7078, IS 18551"
## [13] "N13, IS22380"       "Tx7078, IS22380"    "Tx7078, M35-1"
## [16] "Tx7078, PB1588-3"
```

PEG 0.2, Conductance

```
##  [1] "PB1588-3, 296B"     "ICSV 745, E36-1"    "PB1588-3, E36-1"
##  [4] "Tx7078, E36-1"      "PB1588-3, ICSV 745" "PB1588-3, IS 18551"
##  [7] "PB1588-3, IS 9830"  "PB1588-3, IS22380"  "Tx7078, IS22380"
## [10] "PB1588-3, M35-1"    "Tx7078, M35-1"      "PB1588-3, N13"
## [13] "Tx7078, N13"        "R 16, PB1588-3"     "Tx7078, R 16"
```

PEG 0.2, Intracellular CO_2 fixation

```
##  [1] "E36-1, 296B"       "ICSV 745, 296B"    "IS 18551, 296B"
##  [4] "IS 9830, 296B"     "IS22380, 296B"     "M35-1, 296B"
##  [7] "N13, 296B"         "PB1588-3, E36-1"   "R 16, E36-1"
## [10] "Tx7078, E36-1"     "R 16, ICSV 745"    "IS 9830, IS 18551"
## [13] "PB1588-3, IS 9830" "R 16, IS 9830"     "Tx7078, IS 9830"
## [16] "R 16, IS22380"     "PB1588-3, M35-1"   "R 16, M35-1"
## [19] "Tx7078, M35-1"     "R 16, N13"
```

PEG 0.25, Conductance

```
##  [1] "IS22380, 296B"      "N13, 296B"          "PB1588-3, E36-1"
##  [4] "IS 18551, ICSV 745" "PB1588-3, ICSV 745" "Tx7078, ICSV 745"
##  [7] "IS22380, IS 18551"  "N13, IS 18551"      "PB1588-3, IS 9830"
## [10] "Tx7078, IS 9830"    "PB1588-3, IS22380"  "Tx7078, IS22380"
## [13] "PB1588-3, M35-1"    "PB1588-3, N13"      "R 16, N13"
## [16] "Tx7078, N13"
```

PEG 0.25, Intracellular CO_2 fixation

```
##  [1] "IS 9830, 296B"      "M35-1, 296B"        "Tx7078, E36-1"
##  [4] "N13, ICSV 745"      "Tx7078, ICSV 745"   "N13, IS 18551"
##  [7] "PB1588-3, IS 18551" "Tx7078, IS 18551"   "N13, IS 9830"
## [10] "PB1588-3, IS 9830"  "R 16, IS 9830"      "Tx7078, IS 9830"
## [13] "N13, IS22380"       "Tx7078, IS22380"    "N13, M35-1"
## [16] "PB1588-3, M35-1"    "Tx7078, M35-1"
```